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AOARD REPORT

Japanese Remote Sensing Organizations, Research, and Technology

June 14, 1994
Captain Franklin P. Mills
USAFR

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Asian Office of Aerospace Research and Development (AOAORD)

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Executive Summary

In the mid-1980s, the Japan Ministry of International Trade and Industry (MITI) initiated a space-based non-renewable resource (i.e., petroleum and minerals) exploration effort with the Japan National Space Development Agency (NASDA). MITI's increased funding since that time for resource exploration, space technology, and international research projects indicates a desire to develop a world-wide remote sensing capability that can further expand Japan's political and economic ties with resource-rich developing countries. MITI is also strongly encouraging commercial exploitation of satellite remote sensing, but it is not clear whether Japanese companies will respond. If Japanese companies fully exploit the opportunities provided, MITI's financial and political support may give them a significant competitive advantage in developing country markets. This report provides an overview of MITI's (and some other) remote sensing programs. It includes descriptions of the organizations, an evaluation of their active research efforts, an assessment of Japanese infrared remote sensing technology, and a discussion of near-future directions for Japan's space programs.

Generally, scientific research at MITI's national laboratories in remote sensing is of poor quality when compared to the scientific research underway at Japanese universities. Remote sensing research in Japanese universities, based on a very limited sample, appears limited by funding for personnel, computing resources, and equipment for data collection (e.g., satellite and airborne imagery). Research efforts of particular interest to the US Air Force are (1) the theoretical modeling of multiple scattering between an inhomogeneous surface and the atmosphere by Dr. Takashima at the Meteorological Research Institute, (2) regional climate modeling studies at the Center for Climate System Research (CCSR), and (3) radiative transfer modeling and aerosol remote sensing retrieval studies by Prof. Nakajima at CCSR.

Technology development, in general, at MITI's laboratories (particularly the Electrotechnical Laboratory) appears to be good. In addition, Japanese companies appear to be strong in precision manufacturing and quality control. However, the commercial (non-military) technology for space-based remote sensing in Japan appears to be roughly one to two generations behind the capabilities of NASA's and DoD's contractors. This includes infrared detectors, space-qualified cryocoolers, space-qualified data recorders, satellite command and control, and optics. Consequently, MITI has begun encouraging development of remote sensing technology by Japanese companies. One vehicle has been collaboration with NASA on projects that will provide opportunities for Japanese engineers to learn skills in designing and testing satellite remote sensing instruments.

Current MITI and NASDA projects (most joint with NASA) will give Japan a space-based remote sensing capability comparable to the commercial capability of any other nation: 15 meter sampling in the visible region, 30 meter sampling in the 1 - 3 micrometer region, 90 meter sampling in the 8 - 12 micrometer region, and same-orbit stereo imaging in the visible region. Japan's numerous planned Earth observing missions in the next decade provide many opportunities for technology development and on-orbit testing so differences between the US and Japan in remote sensing technology may narrow.

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List of Acronyms

AAS	Airborne ASTER Simulator
ADEOS	Advanced Earth Observing Satellite
AFOSR	Air Force Office of Scientific Research
AIST	Agency of Industrial Science and Technology (MITI)
AOARD	Asian Office of Aerospace Research and Development (AFOSR)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High-Resolution Radiometer (NOAA Satellite Instrument)
BMDO	Ballistic Missile Defense Office
CCN	Cloud Condensation Nuclei
CCSR	Enter for Climate System Research
CDR	Critical Design Review
CVF	Circularly Variable Filter
DEM	Digital Elevation Model
DMSP	Defense Meteorological Satellite Program (and its satellites)
DoD	Department of Defense (USA)
EERS	European Earth Resources Satellite
EOS	Earth Observing System (NASA and International Program)
EOS-AM1	Early Satellite in the EOS program
EOSAT	US Agency Created by Congress to Operate Landsat
ERSDAC	Earth Resources Satellite Data Analysis Center
ERSDIS	Earth Resources System Data and Information System
ETL	Electrotechnical Laboratory
FWHM	Full-Width at Half-Maximum
GDS	Ground Data System (for ASTER Data in Japan)
Geosat	Consortium of US and International Companies and Organizations for Geological Exploration via Satellite Data (lobbying and scientific research)
GPS	Global Positioning System (USA)
GSFC	Goddard Space Flight Center (NASA)
GSJ	Geological Survey of Japan
IIS	Institute of Industrial Science
IMG	Interferometric Monitor for Greenhouse Gases
ISAS	Institute of Space and Astronautical Science
JAPEX	Japan Petroleum Exploration Company
JAPEX TRC	JAPEX Technical Research Center
JAROS	Japan Observation System Organization
JCDC	Japan Climate Data Centre
JERS	Japan Earth Resources Satellite
JFY	Japan Fiscal Year (April - March)
JGI	Japex Geoscience Institute, Inc.
JICA	Japan Intellectual Cooperation Agency
JMA	Japan Meteorological Agency
JNOC	Japan National Oil Company

JPL	Jet Propulsion Laboratory
LOWTRAN	Low Resolution Atmospheric Transmission Code Developed by PL
LVF	Linearly Variable Filter
MELCO	Mitsubishi Electric Company
MISR	US-built instrument flying on EOS-AM1 with ASTER
MITI	Ministry of International Trade & Industry
MMAJ	Metal Mining Agency of Japan
MODIS	US-built instrument flying on EOS-AM1 with ASTER
MODTRAN	Moderate-Resolution Atmospheric Transmission Code Developed by PL
Monbusho	Ministry of Education, Science, and Culture
MOS	Marine Observation Satellite
MRI	Meteorological Research Institute
MTF	Modulation Transfer Function (Related to Optical Transfer Function)
NASA	National Aeronautics and Space Administration (USA)
NASDA	National Space Development Agency (Japan)
NEC	Nippon Electric Company
NERd	Noise Equivalent Reflectance Difference
NEDT	Noise Equivalent Temperature Difference
NOAA	National Oceanographic and Atmospheric Administration (USA)
OCLI	Optical Coating Laboratory, Inc. (USA)
OCTS	Ocean Color and Temperature Scanner
PDR	Preliminary Design Review
PL	Phillips Laboratory (US Air Force)
RESTEC	Remote Sensing Technology Center
SAR	Synthetic Aperture Radar
SPOT	French Earth Observing Satellite
STA	Science and Technology Agency
SWIR	Short-Wave Infrared Radiometer (Part of ASTER)
TIR	Thermal Infrared Radiometer (Part of ASTER)
TM	Landsat Thematic Mapper
TOPCON	Optical Filter Manufacturing Company (Japan)
TRC	Technical Research Center (JNOC)
TRIC	Tokai University Research & Information Center
TRMM	Tropical Rainfall Measuring Mission
TSIC	Tokai University Space Information Center
USGS	US Geological Survey
VNIR	Visible and Near-Infrared Radiometer (Part of ASTER)

Abstract

Remote sensing research and satellite remote sensing technology have been selected by the Japanese government for government-sponsored commercial development. This report provides an overview of some of the remote sensing programs sponsored by the Ministry of International Trade and Industry (MITI), the National Space Development Agency (NASDA), and the Ministry of Education, Science, and Culture (Monbusho). It describes many of the key organizations, evaluates some of their research efforts, and assesses Japanese infrared remote sensing technology.

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I. Introduction

Remote sensing in its most general meaning encompasses measurements made without physical contact between the sensor and the object. The more specific aspect that is the focus of this report is that of measurements of the earth's surface and atmosphere from space. Remote sensing has many applications, e.g., estimating crop yields, monitoring rain forests, oil exploration, and fighting forest fires. Remote sensing is, also, a classical dual-use technology, and, with the end of the Cold War, technology (and data) that was once restricted to military use is becoming available commercially. Commercial remote sensing (for non-weather applications) from space largely began with the launch of Landsat-1 in 1972. Since that time, commercial remote sensing satellites have been launched by many countries, but the primary ones are the USA, France, Canada, Europe, and Japan. Recently, Russian groups have begun marketing data from their satellites, as well. This report on remote sensing activities in Japan is based on my experience working for three years as an employee of a Japanese government contractor on several projects related to the Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER), a facility instrument for NASA's EOS-AM1 satellite being built under the direction of MITI. Consequently, it is necessarily limited by my experience, my lack of contact with programs sponsored by other agencies of the Japanese government, and my inability to read Japanese.

Remote sensing research and development in Japan is divided among a number of public and private organizations. Section II of this report describes many of the government or quasi-governmental organizations, and Section III gives brief descriptions of some important private (or semi-private) Japanese companies in the field. Section IV is my evaluation of the current status of remote sensing research and technology in Japan, and Section V gives my assessment of the future directions of remote sensing in Japan. This assessment focuses on the remote sensing programs sponsored by Japan's Ministry of International Trade and Industry (MITI), so it concentrates on technology and industrial development, not on space science. Interested readers are referred to the overview of Japanese space policy published by Johnson-Freese (1992). Her report focused on the (primarily space science) work by the National Space Development Agency of Japan (NASDA) and the Institute of Space and Astronautical Science (ISAS).

II. Japanese Government Organizations Involved in Remote Sensing Projects

The three high-level government organizations responsible for funding most remote sensing research in Japan are the Science & Technology Agency (STA), the Ministry of Education, Science, & Culture (Monbusho), and the Ministry of International Trade & Industry (MITI). Other ministries and institutes are involved in specific projects, such as the Environment Agency and the Ministry of Posts and Telecommunications. The Japanese government's budget for remote sensing projects has steadily increased over many years. Accompanying this increase in funding has been a development of "in-country" space technology and management expertise.

STA's primary focus (through its subsidiary NASDA) has been development of the Japanese space technology base. NASDA in the past few years has broadened its mission to include Earth science (and is sponsoring several satellites for environmental and atmospheric studies), but technology development (e.g., communications, rocket boosters) remains its highest priority. NASDA has developed large launch vehicles, ground stations for tracking and communications, and other infrastructure necessary for

commercial space applications. NASDA developed the first Earth observation satellites made in Japan, the Marine Observation Satellites (MOS-1 and MOS-1b), from 1980 - 1985 and launched them in 1987 and 1990. NASDA prepared the bus of the Japan Earth Resources Satellite (JERS-1) and launched it 1992. Currently, NASDA is making the bus and two instruments for the Advanced Earth Observing Satellite (ADEOS) and is collaborating with NASA on the Tropical Rainfall Measuring Mission (TRMM) satellite. NASDA also has underway several satellite engineering test programs, cooperative projects with Japan's Meteorological Agency (JMA), new launch vehicles, and the Japanese Experimental Module (JEM) for NASA's space station. (NASDA 1991 - 1993)

Monbusho pays faculty salaries at all public universities so it finances a lot of published research. However, Monbusho often provides only limited money for university research facilities so faculty are forced to seek outside contracts if they require materials for their research. As a result, remote sensing faculty often serve on advisory committees for STA and MITI so they can steer grants to their research group. Monbusho has created special research institutes, such as the Institute of Space and Astronautical Science (ISAS), the National Astronomical Observatory, and the Center for Climate System Research (CCSR) that are nominally under direct control of Monbusho (rather than under the control of a university). CCSR is active in numerical modeling of the atmosphere and climate, and many CCSR members are part of the science teams for NASDA's environmental and atmospheric research satellites. ISAS has primary responsibility for small launch vehicles and satellites for space science. ISAS has been very successful with low-budget, low-overhead, limited-objective missions. Their success (and encouragement from US scientists) may lead to an unmanned mission to Mars in this decade. Aside from the obvious prestige factor, an interplanetary mission might encourage significant advances in Japanese space technology (e.g., long-term survivability and on-board automation). New capabilities in these areas should also improve Japanese factory automation and product reliability.

MITI is a relatively new player in remote sensing, and its role has expanded significantly since 1985. MITI now has many organizations involved in Earth remote sensing with the goals of advancing the state-of-the-art in Japanese technology, encouraging industrial development, and ensuring economic security. The Earth Resources Satellite Data Analysis Center (ERSDAC) and the Japan Resources Observation System Organization (JAROS) are MITI's primary links to private companies for remote sensing . MITI's national laboratories are active in some areas of remote sensing research and provide technical advice and oversight for hardware and software development. MITI's recent move into Earth remote sensing has conflicted with NASDA's "traditional" space applications role, but MITI's political (and monetary) influence has usually prevailed. The following sections of this report provide an overview of some of the organizations working on remote sensing projects in Japan.

II.A. Non-Profit Foundations Affiliated with MITI and NASDA Engaged in Remote Sensing

MITI and STA have established, in cooperation with private Japanese companies, three quasi-governmental organizations for advancement of remote sensing technology and research: the Earth Resources Satellite Data Center (ERSDAC), the Remote Sensing Technology Center of Japan (RESTEC), and the Japan Resources Observation System Organization (JAROS). ERSDAC is a non-profit foundation directed by MITI; RESTEC is a non-profit foundation under the direction of NASDA; and JAROS is a joint

organization established by MITI and STA. I am not certain of the financial and legal arrangements for ERSDAC and RESTEC, but funding for the annual research projects is provided primarily by MITI and NASDA, respectively. Other government agencies fund projects they are sponsoring, and each foundation has over 30 private companies that are considered sustaining members. These sustaining members, I believe, have contributed capital to the foundation in a manner similar to a joint venture. The legal status of JAROS is similar to that of NASDA with most funding provided by MITI.

The official goals of these organizations are advancement of remote sensing technology and research. Unofficially, ERSDAC and RESTEC (and maybe JAROS) were established to direct money from MITI and NASDA to the sustaining members via contracts. These foundations are informally controlled by MITI/NASDA, but, legally, they are private organizations which must compete for funding from MITI and can then subcontract the work for their projects to any company they wish. The foundations' private-sector status gives them contracting flexibility that is not available to official government agencies. MITI's remote sensing projects have been executed, primarily, through ERSDAC and JAROS with technical support and oversight from MITI's national research laboratories.

II.A.1. Earth Resources Satellite Data Analysis Center (ERSDAC)

ERSDAC was created in 1981 as a non-profit foundation under the Space Industry Division (Machinery and Information Industries Bureau) of MITI with primary funding from Japan's oil import tax through MITI's Agency of Natural Resources and Energy. (Its sustaining members, as of 1992, include 15 resources industries companies, 13 space or computer industries companies, and 10 trading or aerial survey companies.) It was established to develop geological remote sensing analysis techniques, to promote remote sensing applications for resource exploration, and to sponsor remote sensing "training" projects for Japanese companies. (ERSDAC 1993) Consequently, its projects tend to be relatively low budget. ERSDAC was intended to be an advocate for the remote sensing user community (where users are defined as companies exploring for non-renewable resources) within MITI. ERSDAC's policy committee in 1993 discussed broadening ERSDAC's charter to include the environment and other applications of remote sensing so ERSDAC's focus may gradually change over the next decade.

Two of ERSDAC's primary functions are to sponsor research on remote sensing applications and to promote use of remote sensing by Japanese corporations. ERSDAC normally allocates at least one research contract each year to an oil exploration company (e.g., JAPEX or JGI) and at least one contract to a mineral exploration company (e.g., Dowa Mining, Mitsubishi Metal, Mitsui Mining & Smelting, Nippon Mining, Nittetsu Mining, or Sumitomo Metal Mining). These studies provide government-subsidized training in remote sensing data analysis, ground-truth fieldwork, and laboratory sample measurements. For example, ERSDAC used one of its research contracts to sponsor development of a visible-infrared mineral spectra research laboratory at Dowa Mining. This facility largely duplicates facilities at JPL and Johns Hopkins University. ERSDAC has requested money from MITI for JFY 1994 (beginning Apr 1994) to build a visible to infrared sensor calibration facility in Japan similar to the one at NASA's Stennis Space Center. This facility, initially, will be used for testing the AAS, but, with minor modifications, the same facility can be used for testing later generations of airborne optical imaging systems. Some ERSDAC studies have been used to determine appropriate specifications for satellite instruments (e.g., JERS-1 and ASTER). As an example,

ERSDAC and Geosat co-sponsored remote sensing simulation studies using ground and airborne data to verify the ability of JERS-1 to discriminate particular mineral spectral features. Other projects sponsored by ERSDAC have sought to develop new interpretation techniques for remote sensing data. ERSDAC has sponsored remote sensing studies by Japanese companies in Honduras, the US, Yemen, and Australia.

As part of its promotion of remote sensing, ERSDAC has joint projects with several other Japanese government organizations. ERSDAC is working with NASDA and JAROS on the JERS-1 and ASTER projects; with JNOC on oil exploration in Saudi Arabia and China; with MMAJ on mineral exploration; and with JICA on international development projects in developing countries (e.g., Algeria, Peru, Indonesia, and China).

Another primary function of ERSDAC is to archive and to process data from remote sensing satellites. Both NASDA and ERSDAC have acquired and archived data from Landsat, SPOT, JERS-1, EERS-1, and other satellite sensors. NASDA's archive is primarily data collected by the Japanese receiving stations. ERSDAC's archive emphasizes areas with potential petroleum or mineral reserves, such as large geological basins. However, ERSDAC will attempt to create a satellite-imaged map of all land surfaces based on JERS-1 (radar, VNIR, and SWIR) and ASTER (VNIR, SWIR, TIR, and stereo) data. ERSDAC's data is primarily available for Japanese resource exploration companies, but has been provided to Geosat and JPL researchers in response to special requests. MITI has not determined data access policies for ASTER, but, currently, MITI plans to provide ASTER data only to organizations that are working with ERSDAC on research projects and about 300 principal investigators.

ASTER data processing will be done by ERSDAC. Its Earth Resources System Data and Information System (ERSDIS) will be upgraded to the ASTER Ground Data System (GDS) between 1994 and 1997. The ASTER GDS will include a data processing facility and an ASTER instrument flight operations center and will interface to NASDA, NASA, and several other agencies. The data processing facility will receive level 0 (raw) data from the US, process it to level 1 (radiometric and geometric correction) using proprietary software, and transfer the level 1 data to the US. The GDS will also process higher level data products for distribution within Japan. Data processing algorithms will be developed by the joint US-Japanese Science Team and contractors at Japanese companies or universities. ASTER instrument operations will be scheduled and controlled by ERSDAC based on algorithms and priorities from the Science Team.

A fourth primary function of ERSDAC is to advise on the development of new remote sensing instruments. For example, the science teams for ASTER and JERS-1 were organized by ERSDAC. Typically, science team members are drawn from university faculty, national laboratories (primarily MITI's), and contractors working with ERSDAC. ERSDAC managers control the science team budgets with advice from senior science team members and MITI bureaucrats.

Some results from research sponsored by ERSDAC: (1) an automatic lineament extraction algorithm to identify metal mining sites, (2) a local adaptive contrast stretch algorithm for better interpretation of geological structures, (3) SAR data processing algorithms, (4) a multispectral image processing algorithm that was able to distinguish limestone and dolomite reflectance features in surface geologic materials at 2.33 and 2.30 micrometer, respectively, in airborne scanner data from one test site, (5) a library of laboratory spectral measurements of rocks and minerals, (6) field experiments on microwave penetration of tree canopies, and (7) case studies on over 30 oil/gas fields and metallic mineral deposits. (ERSDAC 1993) ERSDAC's research contracts have significantly increased the remote sensing abilities of Japan's resource exploration

companies and have developed facilities that are not available (at similar cost) to most multinational oil and mining companies.

II.A.2. Remote Sensing Technology Center of Japan (RESTEC)

RESTEC is a non-profit foundation under the aegis of NASDA and STA that is similar to ERSDAC. RESTEC was established in 1975 for the purposes of research, development, and dissemination of remote sensing and other space technologies. A primary effort has been to support NASDA's satellite data acquisition and processing. RESTEC has also worked with JICA to offer training courses on remote sensing in developing countries, initiate cooperative research projects with these countries in remote sensing, and to train specialists from these countries during short-term (less than one year) stays in Japan. RESTEC has also helped determine specifications for NASDA instruments, such as the Ocean Color and Temperature Scanner (OCTS) on ADEOS. RESTEC had about 130 employees in April 1993, many of whom are on loan from the 31 sustaining member companies (as of April 1993). They receive training in remote sensing data processing and analysis under the sponsorship of STA during their extended (one - three year) employment period at RESTEC. (RESTEC 1993)

RESTEC's research projects have been directed toward land survey, agriculture and fishery resources monitoring, disaster prevention, and monitoring of environmental changes. Examples of the analysis work done at RESTEC include: (1) estimating global vegetation changes using NOAA-AVHRR global vegetation index data, (2) determining changes in tropical forest land area, (3) combining digital terrain modeling with multispectral data to determine correlations between vegetation and elevation, (4) classifying land cover in urban/suburban areas in Japan, (5) investigating crop yield and crop acreage in Japan, (6) studying sea surface temperatures to map ocean currents, (7) monitoring the distribution of sea ice near Japan, and (8) geocoding SAR data to determine topography and geomorphology. (RESTEC 1993)

II.A.3. Japan Resources Observation System Organization (JAROS)

JAROS was founded in 1986 as a joint venture of MITI's Space Industry Division and STA. JAROS is, legally, a private-sector organization like NASDA, but its funding is provided, primarily, by MITI and most of its directors are from similar quasi-governmental agencies. Its predecessor was created to manage development of the payload instruments for JERS-1. JAROS took over development of the JERS-1 payload instruments as part of its broader mission to stimulate development of systems for resource exploration (field-portable, airborne, and spaceborne). JAROS's charter now includes advancing Japanese space technology, securing a stable supply of natural resources for Japan, and improving technology for monitoring the environment from space. (JAROS 1991)

MITI gave JAROS responsibility for developing the payload instruments for JERS-1 and ASTER. Specifications were determined by consultation with MITI's national laboratories and ERSDAC, then JAROS has managed the hardware development. On completion of the hardware development, JAROS will give the instruments to ERSDAC for operation, maintenance, and practical application.

In addition to the satellite instruments, JAROS has financed development of an Airborne ASTER Simulator (AAS) which was originally intended for use in determining the final specifications of the TIR subsystem of ASTER and for researching the TIR characteristics of geological materials. This simulator is being built by a US company with some components from Japanese companies. (The primary reason a US company was selected is that no Japanese company was willing to attempt the project within JAROS's budget.) MITI has decided that data from the AAS will be available, initially, only to ASTER Science Team members and, later, only to researchers working on cooperative projects with ERSDAC.

The first of JAROS's next-generation projects is a conceptual study of a multi-band, multi-polarization SAR that includes L-band and a variable off-nadir illumination angle. If funding is approved, this conceptual study will be followed by development of an airborne SAR and satellite-borne SAR with similar characteristics. JAROS's other next-generation project is an improved version of IMG that can determine the behavior of greenhouse gases from creation to extinction. Funding for a conceptual study for an IMG-II was requested in JAROS's JFY 1993 proposal to MITI. Farther into the future, JAROS has discussed development of an advanced version of ASTER. Conceptual studies for this instrument will likely begin after ASTER is launched. (JAROS 1993)

II.A.4. Personnel in the Non-Profit Foundations (ERSDAC, RESTEC, and JAROS)

Japan has had a lifetime employment system since the end of WWII. The employment guarantee, however, has never implied anything about the type or location of work. Many employees are hired by one company but actually work in a different, affiliated company. Pay and benefits are set by the hiring company but working conditions are set by the affiliate. This system was modified about five to ten years ago to accommodate temporary employment agencies who recruit (primarily) clerical workers for companies. In the past couple years, the economic slowdown in Japan has led some major corporations to transfer permanent employees to companies which are not affiliates.

The Japanese government has had a slightly different employment system. Almost all ministry- or agency-level employees are career civil servants hired by that ministry or agency. The upper management employees of quasi-governmental agencies and government-affiliated non-profit foundations are also, primarily, career civil servants from the ministry that sponsors the agency or foundation. At the middle management and staff echelons, these organizations' workers are a mixture of employees of the organization, retired civil servants hired by the organization, and employees on loan from the private companies that receive contracts from the organization. In the technical departments, most of the workers at these organizations are on loan from private companies. In this respect, JAROS and ERSDAC are typical of these quasi-governmental organizations.

II.A.4.a. ERSDAC, RESTEC and JAROS Employees

JAROS, RESTEC, and ERSDAC were created as partnerships between Japanese government agencies and private companies. One of their primary (unofficial) purposes is to funnel money from the government to selected private companies for research and technology development. The employee loan system furthers this goal and creates an interdependence between the private companies and ERSDAC/JAROS/RESTEC: (1) ERSDAC/JAROS/RESTEC do not have to provide basic training to workers since all loaned employees have worked for at least a couple years at their home company; (2) additional training received at ERSDAC/JAROS/RESTEC flows back to the home companies; (3) ERSDAC, RESTEC, and JAROS have access to an adjustable pool of workers, and companies avoid laying off excess employees during economic downturns; (4) loaned employees are able to help direct ERSDAC/JAROS/RESTEC research contracts to their home companies; (5) loaned employees develop personal contacts with ERSDAC/JAROS/RESTEC employees that, later, help win contracts for their companies. Loaned employees typically work at ERSDAC, RESTEC, or JAROS for 2 - 4 years then return to their home company.

II.A.4.b. ERSDAC and JAROS Project Oversight Committees

ERSDAC and JAROS rely on outside technical expertise for their project oversight committees and science teams. Committee members are drawn primarily from government agencies (such as the Geological Survey of Japan and the Geographical Survey Institute) and universities. Some committee members are researchers in private companies (such as JGI) and one - two people on each committee are ERSDAC/JAROS employees. Most of the university representatives are drawn from the University of Tokyo, primarily as a result of proximity and Monbusho politics. ERSDAC and JAROS provide a nominal fee, as transportation expense, to all technical review committee members but no salary support. Consequently, the committees are considered additional duties for the members. Unlike NASA, this is also true for science team members in Japan. The science team member's home organization continues to pay the member's salary and controls the amount of time the science team member may devote to ERSDAC's science team. Team member's are usually relieved of some duties in their home organization in the hope that the home organization will receive contracts from ERSDAC, but science teams in Japan are still considered as an additional duty.

ERSDAC relies heavily on private companies for support of its technical committees. Two contracting companies providing significant technical support to ERSDAC are the Japex Geoscience Institute (JGI) and the Mitsubishi Research Institute. These companies help ERSDAC host scientific meetings, help ERSDAC's technical advisory committees prepare specifications for contracts and Requests for Proposals, and have loaned several employees, each, to ERSDAC.

JAROS seems to rely more on government research laboratories for expertise rather than private companies. Several people from the Electrotechnical Laboratory and the National Research Laboratory of Metrology support JAROS committees with salary support from their laboratory.

RESTEC works in support of NASDA so RESTEC does not have many contracts it awards to outside companies.

II.B. Other Quasi-Governmental Organizations Affiliated with MITI

ERSDAC, RESTEC, and JAROS are examples of quasi-governmental organizations. These organizations are considered, legally, as private foundations or corporations, but almost all of their funding is provided by the Japanese government, a majority of the corporate stock is held by the government, and the government usually specifies the organizations' annual activities. Two other organizations that are financing remote sensing research are the Japan National Oil Company and the Metal Mining Agency of Japan. These organizations do not have any in-house research on remote sensing but fund research projects by private companies.

II.B.1. The Japan National Oil Company (JNOC)

JNOC primarily functions as an administrative body supporting all Japanese oil companies and collecting revenue from Japan's national petroleum tax. However, it does have a seismic data processing and analysis group that works on international joint projects with other governments (e.g., the Algerian National Oil Company). It also has its own Technical Research Center (TRC) located in Makuhari (near Tokyo). The TRC focuses on basic and applied research related to petroleum formation, exploration, and exploitation. TRC recently began sponsoring an annual international conference on oil formation conditions and physical characteristics of petroleum reservoirs.

II.B.2. The Metal Mining Agency of Japan (MMAJ)

MMAJ is similar to JNOC but it supports Japanese mineral exploration companies.

II.C. MITI National Laboratories Engaged in Remote Sensing Research

MITI has established 16 research institutes under the Agency of Industrial Science and Technology (AIST). Nine of the national laboratories are located at the Tsukuba Research Center: National Research Laboratory of Metrology (NRLM), Mechanical Engineering Laboratory, National Chemical Laboratory for Industry, Fermentation Research Institute, Research Institute for Polymers and Textiles, Geological Survey of Japan (GSJ), Electrotechnical Laboratory (ETL), Industrial Products Research Institute, and National Institute for Resources and Environment. A Government Industrial Development Laboratory is located in Hokkaido and six Government Industrial Research Institutes are located throughout Japan. (AIST 1991) Three of these national laboratories (NRLM, GSJ, and ETL) are actively supporting remote sensing projects. GSJ has provided many of the JERS-1 and ASTER Science Team members who are responsible for selecting and/or developing data analysis algorithms, mission operations procedures, and the ASTER Ground Data System design. Researchers from ETL and NRLM are the leading members of the Engineering Team for JERS-1 and ASTER. They are responsible, within the budget guidelines set by MITI and JAROS, for managing development of the sensors and they conduct the Design Reviews (PDR and CDR). In addition, NRLM is assisting with the sensor testing and performance evaluation. Following are brief descriptions of research areas at GSJ and ETL. I visited researchers at both facilities but did not receive a tour so this information is drawn, largely, from the laboratories' English

pamphlets. NRLM is not included because I am not familiar with its work. Several NIST researchers visited NRLM and ETL in 1993 and should be familiar with their facilities and activities.

II.C.1. Geological Survey of Japan (GSJ)

GSJ was founded in 1882 to survey the geology of the Japanese Islands. Its mandate has broadened to now include a wide range of studies in the Earth sciences. The research staff of 230 people had a total operating budget (excluding personnel expenses) of about Yen 1.8 billion (US$ 17 million at exchange rate of Yen 105/US$) in 1992. 95% of GSJ's budget was allocated to basic research (including laboratory administration), AIST special projects, geothermics development, and STA research projects. (GSJ 1990 & 1993)

One of GSJ's two primary research areas is understanding and mapping the geology of Japan and the surrounding continental shelf. This research includes mapping the island geology at the scale of 1:50,000; stratigraphic, tectonic, and petrologic studies of island-arc and fore-arc regions; mapping the geology of the continental shelf and slopes around Japan at a scale of 1:200,000; compilation of nationwide gravity maps; an aeromagnetic survey of the continental shelf and slope; a nationwide assessment of geothermal resources; geological study of earthquake regions (including earthquake prediction); and geological, geochemical, and geophysical studies of active volcanoes. (GSJ 1990)

The other primary area of research for GSJ is exploration for and development of energy resources and minerals. Projects in this area include: metal concentration mechanisms in high-temperature hydrothermal systems, three-dimensional modeling approaches for resource assessment, remote sensing techniques for geological exploration, techniques for locating rare minerals, procedures for developing resources that are buried at great depths, assessment of the mineral potential of regions (worldwide, not just in Japan), models of hydrothermal systems to predict behavior during and after geothermal production, estimation of the formation conditions required for generation of hydrocarbon deposits, and development of technology for evaluating potential geothermal or hydrocarbon reservoirs. (GSJ 1990)

Secondary areas of research at GSJ include fundamental geological processes and environmental issues. A couple examples are laboratory measurements of rock fracturing in earthquakes using acoustic emission techniques and geochemical studies on major and minor elements and isotopes in rocks and minerals. Environmental projects include the absorption of CO_2 by coral reefs, long-term stability of sites for nuclear waste disposal, and diffusion of industrial pollutants into soil, rock, and water. (GSJ 1990)

The Science Team leader for ASTER, Dr. Hiroji Tsu, was a section manager at GSJ and many researchers in GSJ's remote sensing and geothermal research sections were selected as chairmen of technical working groups for the ASTER Science Team. Dr. Tsu, in 1993, was transferred from GSJ to ERSDAC for the duration of the ASTER project.

II.C.2. Electrotechnical Laboratory (ETL)

ETL was founded in 1891 and is active in basic and applied research. The main fields of study include advanced electronics, information processing technologies, energy technologies, and national standards and measurement technologies for electricity, light, radioactivity, and sound. As of 1992, ETL had a research staff of 545 people and total budget of $77 million (one-half of which was for personnel expenses). Five areas

accounted for about 75% of the non-personnel (operating) budget: nuclear, energy, future industries, "special," and fundamental research. (ETL 1992)

Significant research efforts were underway (in 1992) on material properties, material synthesis, new technologies for material processing and measurement, very high speed digital and analog electronic devices, new high-temperature superconducting materials, applications for high-temperature super-conducting materials, laser technologies and applications, potential new energy resources and utilization of energy (conversion, transportation, storage), robot technology, machine processing of information for autonomous operation and pattern recognition, and standards measurements for electromagnetic phenomena. (ETL 1992)

Dr. Hiroyuki Fujisada is the co-leader of the ASTER Engineering Team (with Dr. Akira Ono of the National Research Laboratory of Metrology and Dr. Masahiko Kudoh of JAROS). His research specialty is infrared sensor development. He was working with Hamamatsu Photonics on a low noise linear InSb array detector in 1991 (Fujisada et al. 1990) when I visited his laboratory. At that time, he claimed the NEDT was less than 0.02 K (Fujisada 1991), but the demonstration he gave us had significant (appeared to be ~0.1 - 0.5 K equivalent) pattern noise due to the differential gains for each element of the array. Consequently, the NEDT could not be verified.

II.D. Research Institutes and Centers of the Japan Meteorological Agency (JMA)

The Japan Meteorological Agency (JMA) has responsibility for not only meteorological assessment and warnings but also earthquake and volcanic eruption warnings. In support of this civil defense role, JMA has a network of about 120 observation stations for monitoring potential volcanic eruptions and earthquakes. About 20 of the most active volcanoes are monitored constantly. JMA also had (in 1992) 6 observational vessels and over 70 tide-gauge stations. It also has an associated research institute, the Meteorological Research Institute (MRI), and a recently-established data center, the Japan Climatic Data Center (JCDC). I have not had any contact with JMA or JCDC and have met with only one researcher from MRI so the following descriptions are based, primarily, on publicly-available English pamphlets for these organizations.

II.D.1. Meteorological Research Institute (MRI)

MRI was founded in 1942 as the research division of the central meteorological observatory. After several reorganizations and moves, it is now located at Tsukuba, near the AIST research complex. MRI had about 150 researchers in 1992 with an annual budget of about Yen 3.1 billion (US$ 15 million). General areas of research interest are weather forecasting techniques, climatic change mechanisms, tropical meteorology and typhoons, rainfall and snowfall mechanisms, the atmospheric boundary layer, environmental and industrial meteorology, meteorological satellites and weather observation systems, prediction of earthquakes and volcanic eruptions, oceanography, and geochemistry. Numerical models are developed to integrate the results of theoretical calculations, laboratory studies, remote sensing measurements, and in-situ measurements. (MRI 1992)

Specific research efforts include numerical simulations of heavy precipitation and the effects of orography on precipitation; low altitude wind shear near airports; long-range weather forecasts and climate studies; genesis, development, structure, and movement of tropical disturbances; microphysics of cloud droplet growth and precipitation; numerical simulations and experimental verification of local climatology; and measurement and modeling of the Pacific Ocean circulation. (MRI 1992)

Laboratory facilities include a large meteorological wind tunnel (2 x 3 x 18 m) for simulations of the atmospheric boundary layer; a 6 m diameter turntable and circular wind tunnel for study of the effect of rotation on fluid motion; an absorption gas cell with an effective path length of 1 km; a transmission electron microscope, X-ray fluorescence spectrometer, mass spectrometer, and FTIR for composition analysis of air, particulate, and water samples; a 200 m tower for in-situ measurements of the local boundary layer; and two tunnels for studying the interactions of wind and waves. Other facilities include a 200 MW output LIDAR (694.3 nm) with 80 cm collector, fixed-location and portable Doppler radars, an Earth tide gravimeter, and cold environment simulator rooms. Ocean-bottom seismographs and other earthquake and volcano monitoring equipment have been developed and deployed. (MRI 1992)

Several MRI researchers are members of the ASTER Science Team. Under the direction of Dr. Tsutomu Takashima, they are working on atmospheric-correction algorithms for deriving land surface radiance from calibrated satellite data. Dr. Takashima has been active in developing radiative transfer models for satellite measurements of an inhomogeneous surface through a plane-parallel, multi-scattering atmosphere. Current versions of LOWTRAN and MODTRAN incorporate multiple-scattering algorithms for the atmosphere but do not include the effects of multiple scattering between the land surface and atmosphere. Dr. Takashima's models incorporate these surface-atmosphere multiple scattering effects which are important for spectral identification of surface materials.

II.D.2. Japan Climatic Data Centre (JCDC)

JCDC was created in 1990 to be a repository for climate data for JMA and was designated as the World Meteorological Organization's repository for data on greenhouse gases. It seems to be a data processing and archiving center with no active research. (JCDC 1993)

II.E. Ministry of Education, Science, and Culture (Monbusho) Research Centers

Monbusho sponsors a large amount of remote sensing research through its national research laboratories and the national universities. Funding, however, is often limited to only the researcher's salary. Four organizations focusing on particular applications of remote sensing or development of particular remote sensing technologies are the Institute of Space and Astronautical Science, the Center for Climate System Research, the Institute of Industrial Science, and the Tokai University Space Information Center. Tokai University, Kanagawa University, Chiba University, the University of Tokyo, and other universities have active programs. The two professional societies that include most remote sensing researchers in Japan are the Remote Sensing Society of Japan and the Japan Society of Photogrammetry and Remote Sensing.

II.E.1. Institute of Space and Astronautical Science (ISAS)

This institute, formerly part of the University of Tokyo but now a national research institute, is well-known and very active in space science. ISAS has been very successful with low-budget, low-overhead, limited-objective space science missions, similar to the approach currently being advocated by NASA headquarters. Further information on ISAS can be found in Johnson-Freese (1992).

II.E.2. Center for Climate System Research (CCSR)

CCSR was founded in 1991 as a national research laboratory which is open for use by researchers at any national university (or similar facility). CCSR is administered by the University of Tokyo, and most of the research staff (10 professors, associate professors, or lecturers) were recruited from the Geophysics Department at the University of Tokyo. CCSR was established to study the earth's climate via development and verification of computer models of the atmosphere, the oceans, the land surface, and the interactions between them. In particular, CCSR was created to focus on Earth and environmental changes in the Asia and Pacific area. Its primary research fields are atmospheric modeling, oceanic modeling, climate modeling, analyzing historical climatic data, comparing predictions from different climate models, and modeling how climate changes can be observed in particular regions. (CCSR 1991)

Current CCSR research topics in atmospheric modeling include: (1) developing a fine-grid atmospheric model, (2) parametrizing sub-grid-scale phenomena such as cumulus convection and boundary layer turbulence, (3) relating convective clouds to large-scale atmospheric waves in the tropics, (4) studying the influence of cloud structure and radiative properties on the general circulation of the atmosphere, and (5) modeling the interaction between the stratosphere and troposphere. (CCSR 1991)

Current oceanic modeling topics include: (1) the relationship between mesoscale vortices and the general circulation of the oceans, (2) the influence of the Antarctic Ocean on circulation patterns in the other oceans, (3) parametrization of oceanic diffusion, and (4) the carbon cycle in the ocean. (CCSR 1991)

Climate modeling topics under study include: (1) integrating atmospheric, oceanic, and land surface models to form a complete climate model, (2) studying the interactions between the atmosphere, ocean, and land surface (such as the El Nino and Southern Oscillation), (3) examining the climate change that would result from environmental changes (e.g., solar insulation and vegetation), (4) examining the impact of greenhouse gases on climate, and (5) interpreting evidence of long-term climatic fluctuations over the last several thousand years. (CCSR 1991)

Other current or recent research projects include: (1) the characteristics of tropical convection, (2) comparisons of convection schemes in different climate models, and (3) the effect of human activities on local climate. (CCSR 1991) Many of CCSR's researchers are members of the ADEOS instrument Science Teams, such as the Improved Limb Atmospheric Spectrometer (ILAS).

Professor Teruyuki Nakajima is studying satellite remote sensing of aerosols and clouds. He has an extensive background in radiative transfer model development, including work at Goddard Space Flight Center on remote sensing of clouds. Current efforts include measurement of cloud-condensation nuclei (CCN) that originate in China

and are carried over the Pacific Ocean, measurement of the changes in cloud properties as CCNs are added to existing clouds (e.g., by emissions from ships passing under the marine cloud layer), and measurement of the effects of volcanic aerosols on clouds. This work is directed toward modeling the climatic effects of cloud formation.

II.E.3. Institute of Industrial Science of the University of Tokyo (IIS)

A division of the University of Tokyo, the IIS, under Professor Mikio Takagi, has built a receiving station in Tokyo for collecting NOAA/AVHRR and other satellite data of Eastern Asia. He archives this data and has done some analysis work, but his primary focus is on developing new concepts for organizing, archiving, retrieving, and disseminating remote sensing data.

II.E.4. Tokai University Space Information / Research & Information Centers (TSIC & TRIC)

Tokai University has developed a group for applying satellite remote sensing data to environmental and natural disaster monitoring. The TSIC in Kumamoto (southern Japan) distributes data via a wide-area network to the main campus in Tokyo (the TRIC) and branches in other locations. (TSIC 1990)

III. Private and Semi-Privatized Japanese Corporations Involved in Remote Sensing Projects

Many Japanese companies are doing some work related to remote sensing. Most are either resource exploration companies (petroleum and minerals) or electronics technology companies. The research groups in the resource exploration companies are usually small, only a few people. Two such companies, however, have had relatively large remote sensing sections, ~10-20 people: Japex Geoscience Institute (JGI) and Mitsubishi Research Institute. Both companies serve a consulting contractors to ERSDAC and receive significant funding from ERSDAC for support of ERSDAC's technical committees. Cuts by MITI in funding for remote sensing research (as opposed to technology development) and the continuing economic slowdown in Japan are triggering increased competition among these contractors so the total number of corporate researchers in remote sensing is likely to decrease over the next five years unless these companies start marketing remote sensing products for other applications, such as environmental or land-use surveys.

The electronics companies have a large engineering staff working on each project. They have benefited greatly from MITI's increased funding for remote sensing technology but face increasing competition from consortia of smaller companies seeking new business.

III.A. Resource Exploration Companies (Geologic Remote Sensing Applications)

Most exploration companies (worldwide) have examined optical or radar remote sensing for exploration work. The general consensus is that remote sensing can be a valuable tool so most companies keep a couple people on staff or hire a subcontractor to

do surveys, but no major mineral or petroleum deposit has ever been located first by optical remote sensing. Consequently, the most common use identified for remote sensing is to plan the logistics for developing a new deposit. (Based on a survey conducted by JGI for ERSDAC in 1992 of major petroleum exploration companies.)

In Japan, MITI (through ERSDAC contracts) has sought to develop remote sensing capabilities at Japanese resource exploration companies. Consequently, most Japanese mining and petroleum exploration companies have established small (~3-4 people) remote sensing groups. These companies include Dowa Mining, Mitsubishi Metal, Mitsui Mining & Smelting, Nippon Mining, Nittetsu Mining, Sumitomo Metal Mining, Imperial Oil, Arabian Oil, and Japan Petroleum Exploration.

III.A.1. Japan Petroleum Exploration Company (JAPEX)

The Japan Petroleum Exploration Company (JAPEX), initially, was founded as a state-owned company for oil exploration and development within Japan. Later, its role expanded to encompass oil exploration outside Japan, and JAPEX has had subsidiaries (or joint venture projects) in Indonesia, Cambodia, Turkey, the USA, and other countries. JAPEX and the Arabian Oil Company provide most of the oil exploration personnel used by Japanese oil companies (via personnel loans and subcontracts) throughout the world. JAPEX is, now, a private company in the same sense as Nippon Telephone and Telegraph--two-thirds of the stock issued for JAPEX is held by JNOC and many of the oil exploration projects undertaken by JAPEX are funded by JNOC. JAPEX has two subsidiaries for research and development--the JAPEX Technical Research Center (TRC) in Makuhari (next door to the JNOC TRC in a Tokyo suburb) and the Japex Geoscience Institute (JGI) headquartered in downtown Tokyo. The JAPEX TRC focuses on basic and applied research related to oil formation, exploration, and extraction.

JAPEX was one of the primary founding members of ERSDAC, and, consequently, ERSDAC, early in its history, awarded many of its contracts to JAPEX. After JAPEX created JGI, ERSDAC's historical tie to JAPEX was transferred to JGI. The tight link between ERSDAC and JGI has steadily eroded as other companies have developed remote sensing sections which compete with JGI for money from ERSDAC.

III.A.2. Japex Geoscience Institute, Inc. (JGI)

JGI was created in 1983 as a wholly-owned subsidiary of JAPEX and most employees of JAPEX's geophysical research department were transferred to JGI. JGI's primary businesses are (1) development of equipment for geophysical exploration (e.g., seismic testing), (2) development of software for processing geophysical data (well logs, seismic data, etc.), (3) seismic data processing, and (4) remote sensing. JGI has subsidiaries and cooperative ventures throughout the world. The remote sensing department of JGI in 1993 was probably the largest corporate remote sensing research group in Japan. This arose from JAPEX's historical role in founding ERSDAC and JGI's position as an advocate for petroleum exploration using remote sensing. JGI is still, arguably, the primary technical support contractor for ERSDAC, and JGI has a number of people who are knowledgeable in visible, infrared, and radar remote sensing.

III.B. Electronics Technology Companies (Remote Sensing Hardware Development)

Most major Japanese electronics companies (i.e., NEC, Mitsubishi, Fujitsu, and Hitachi) have a contract with either NASDA or MITI for building and/or operating remote sensing equipment. NEC is the biggest corporate player and, arguably, the only Japanese company capable of doing system integration for a space mission. NEC has been the system integration contractor on both of MITI's satellite projects and some, maybe all, of NASDA's. NEC has also carved out a niche building visible-region space-based imagers for both JERS-1 and ASTER. Mitsubishi Electric Company (MELCO) made the 1-3 micrometer imagers (PtSi linear arrays) on both JERS-1 and ASTER, the synthetic aperture radar for JERS-1, and the cryocooler for the 1-3 micrometer imager on ASTER. MELCO also designed the mission control system for JERS-1. Fujitsu built the 8-12 micrometer imaging subsystem (HgCdTe) of ASTER, the cryocooler for the 1-3 micrometer imager for JERS-1, and the cryocooler for the 8-12 micrometer imager for ASTER. Fujitsu also designed the system for processing JERS-1 data. Fujitsu is marketing a 110-GHz passive monitoring system for ozone. Hitachi is building the master power supply for ASTER which will draw power from the EOS-AM1 spacecraft bus and convert it for use by all ASTER subsystems.

Other companies are providing components for the satellite subsystems. For example, Hamamatsu Photonics is building 8-12 micrometer detectors for upcoming NASDA missions and made InSb and HgCdTe arrays for the Airborne ASTER Simulator (AAS). TOPCON manufactured 8-12 micrometer linear variable filters for the AAS.

MITI's contracting arrangements for JERS-1 and ASTER seem to have been designed to spread opportunities among the possible competing companies. JAROS (a MITI organization) has direct contracts with each of the four major electronics companies for a subsystem of ASTER rather than awarding a contract for the entire system to a prime contractor (or consortium of companies). This arrangement keeps all companies involved in development of space (and remote sensing) technology, but it may discourage the contractors from sharing information with each other (and with MITI/JAROS) and may discourage the contractors from providing their best efforts on the project (since responsibility is shared among all contractors). It does mean that JAROS must make almost all of the tradeoffs between the demands of the subsystem instruments (VNIR, SWIR, and TIR).

III.C. Asia Air Survey Company (Non-Geologic Remote Sensing Applications)

Asia Air Survey Company is the only Japanese company I encountered that is actively marketing remote sensing for applications other than resource exploration. They do conventional ground surveys, aerial surveys, bathymetric surveys, and mapping. Applications include facility management systems, city administration, road and bridge designs and routings, urban environmental plans, and disaster prevention plans. (Asia Air Survey 1991)

IV. An Assessment of Japanese Remote Sensing Research and Technology

The quality of remote sensing research is closely tied to the quality of the technology used. Good remote sensing research requires specialized technology for collecting data,

data processing equipment, and theoretical (or empirical) models for assimilating and interpreting the measurements. The high level of expertise in the USA results from concerted development efforts in all three areas over the past decades at NASA centers, DoD laboratories, other research centers (such as the Environmental Research Institute of Michigan--ERIM), US universities, and some private companies. Japan, on the other hand, does not seem to have placed a high priority on remote sensing, until recently. As a result, most research in Japan has been limited to small-scale experimental projects that are very closely tied to the Japanese economy (e.g., estimates of rice crop yields, typhoon prediction and tracking) and theoretical algorithm development. Recently, however, Japan has begun to place greater emphasis on remote sensing, has provided greater funding for projects (sometimes using overseas test sites), and computer modeling efforts have become more realistic. The following sections give my assessment of the current state of Japanese remote sensing research and technology (with a much stronger emphasis on technology than on research due to my experience working at a MITI contractor).

IV.A. Remote Sensing Research in Japan

Most remote sensing research in Japan is conducted by university faculty, students, and staff, usually as a one - three person team. Landsat and NOAA AVHRR (Advanced Very-High Resolution Radiometer) satellites are the most common instruments used, and the data is collected by NASDA, the University of Tokyo, or Tokai University when the satellite passes over Japan. Much of this research is reported in Japanese-language journals (so I do not have good information on it), but the English-language abstracts published by the Remote Sensing Society of Japan indicate four types of research predominate: (1) empirical work directed at correlating observed ground conditions with available satellite data, (2) applications that directly relate to life in Japan (e.g., rice crop yields, typhoon tracking), (3) studies of image processing or image-enhancement techniques, and (4) theoretical modeling that is sufficiently simplified so that intense computation is not required. The best research, eventually, appears in English-language journals but this may take several years because of the difficulty many Japanese researchers have in writing an English-language article.

Recently, remote sensing research in Japan has become more quantitative with more extensive ground-truth measurements and attempts to relate observed phenomena to underlying physical processes. A larger fraction of recent Japanese research has addressed regional or global scientific problems (e.g., the environment, tropical deforestation, and global change) or economic issues (e.g., geological exploration). Science teams have been formed for recent and upcoming Japanese remote sensing satellite projects with specific charters to examine these broader issues.

Two groups I encountered that are conducting good remote sensing research projects are the Meteorological Research Institute (MRI) and the Center for Climate System Research (CCSR). Dr. Tsutomu Takashima at MRI has done extensive theoretical and computational work on radiative transfer in a multiply-scattering atmosphere with multiple scatters between a heterogeneous surface and the atmosphere. Professor Teruyuki Nakajima at CCSR has developed radiative transfer models for analysis of satellite measurements of aerosols and cloud particles.

In the MITI scientific community, the quality of research has been lower. The JERS-1 and ASTER projects have been a learning experience for many of the Japanese researchers

involved, bringing them up to the level of their counterparts in US universities. The Japanese ASTER Science Team members are good researchers, but they have had limited experience in remote sensing and are not permitted to devote a significant amount of their research efforts to the ASTER project.

IV.B. Remote Sensing Technology in Japan

Japan is, relatively, a newcomer to the development of Earth remote sensing instruments. Japan's first remote sensing satellites, Geostationary Meteorological Satellite (GMS) and Marine Observation Satellite (MOS-1), were launched in the mid-1980s and JERS-1 was launched in 1992. In addition, few airborne remote sensing instruments have been developed in Japan due, in part, to the cost of maintaining an aircraft in Japan and the legal restrictions on operating a customized aircraft near populated areas. NASDA and MITI, however, seem intent on developing advanced remote sensing instruments and satellites in Japan for Earth observations, and several remote sensing satellites (or instruments) are planned for the late-1990s (e.g., Iwasaki et al. 1991).

The technology used in JERS-1 and MOS-1 does not match the level used in NASA or DoD satellites, but the technology planned for Japan's upcoming systems is only about one to two generations behind that in US systems. Since the Japanese product cycle averages about five to eight years, approximately one-half the time for many US satellite programs, the competitive advantage enjoyed by the US in remote sensing technology may decrease rapidly. In the following sections, I will examine some of the key technologies needed for remote sensing instruments: infrared detectors, cryocoolers, optics, optical filters, data recorders, system integration, project management, precision manufacturing, ground system infrastructure, and testing and standards. These technologies also have applications to other commercial projects and to military equipment.

IV.B.1. Infrared Detectors

I have been told several times that Japanese infrared detectors are much better than those available commercially from US companies. In fact, Japanese companies have captured a large portion of the market for infrared detectors for burglar alarms, automated light switches, etc. However, the direct comparisons I have seen of laboratory-grade and custom-designed detectors indicate the infrared arrays produced by Japanese companies are comparable to, but not significantly better than, those produced by US-based companies. First, tests by the (then) Rome Air Development Center (RADC) in 1989-90 found the PtSi two-dimensional arrays produced by Mitsubishi Electric Corporation (MELCO) were good but not as good as those made by several US companies at that time.

Second, when I visited Dr. Fujisada at ETL in 1991, he demonstrated to us a 128-element linear InSb array produced by Hamamatsu Photonics (Fujisada et al. 1990) with NEDT of 0.02 K (Fujisada 1991). Again, this is good, but it is the same NEDT as was advertised in 1993 by Amber Research for its 256 x 256 InSb arrays (Amber Research 1993). In addition, Dr. Fujisada's array had noticeable "striping" due to the unequal sensitivities of the linear array elements (differences appeared to be ~0.1 - 0.5 K).

Third, two sets of one-dimensional HgCdTe (8-12 micrometer) arrays were made for the Airborne ASTER Simulator (AAS), one set by Graseby and one set by Hamamatsu

Photonics. The original estimate we received from Hamamatsu Photonics was that they could produce arrays with D* values (a measure of detector sensitivity and noise) that were at least 50% better than those of the Graseby arrays. Some elements of the arrays that Hamamatsu produced did have D* values that were almost 50% better than those of the Graseby arrays, but many elements of the Hamamatsu arrays had D* values which were worse than those of the Graseby arrays. The cost for the Graseby arrays was about two-thirds that for the Hamamatsu Photonics arrays. (JGI 1993)

Based on these comparisons, I feel that laboratory-grade and custom-design Japanese infrared detectors have performance comparable to, but not significantly better than US-manufactured infrared detectors. However, it is still possible that Japanese infrared detector manufacturers will not ship their highest-quality arrays outside Japan, thus, making any comparison inaccurate.

IV.B.2. Cryocoolers

Space-qualified cryocoolers are critical for infrared remote sensing at wavelengths longer than about 1-2 micrometer. Many instruments, to achieve high reliability and long lifetimes, have relied on passive radiators, but passive radiators cannot easily achieve the low temperatures (<70K) desired for best performance at longer wavelengths.

One alternative, a mechanical Stirling-cycle cryocooler with clearance free seals, was demonstrated by an Oxford group in the mid-1980's (Davey 1990, Chan et al. 1990). ETL and Fujitsu used the Oxford design as a basis for the JERS-1 1-3 micrometer cryocooler (Ohmori et al. 1991, Kawada & Fujisada 1991). This integral-Stirling-cycle cryocooler met its design goals of >1 W at 80 K with an operating lifetime of >2000 hours during two years on orbit (1992-4) (Kawada & Fujisada 1991). In 1994, Fujitsu and MELCO are scheduled to complete engineering models of their ASTER TIR and SWIR, respectively, cryocoolers. Multiple engineering models are being manufactured and the best ones will be selected as the flight models. Both TIR and SWIR use a split-Stirling-cycle with clearance-free seals, and they are intended for 50,000 hours of operation during five years on orbit (Fujisada and Ono 1993).

As of 1993, the breadboard model tests and engineering model design analysis for the ASTER cryocoolers predicted 1.2 W at 70K of cooling with mass <7 kg (Isoda et al. 1993). The reliability goal for the cryocoolers was ~97%. However, both ASTER cryocoolers, as of 1993, were at least a factor of 10 worse than the desired vibration levels.

A short literature search indicates the Japanese cryocoolers for ASTER do not have some capabilities of cryocoolers under development for the Ballistic Missile Division Organization (BMDO), Phillips Laboratory (PL), and NASA (Stacy 1992), but the Japanese design has been successfully tested in space and surpasses some capabilities of the BMDO cryocooler. Three designs using diaphragms were in progress at Creare, Inc., as of 1991: (1) 2 W at 65 K cooling with 10 kg mass and intended life of 10 years at 95% reliability for BMDO and PL, (2) 300 mW at 30 K cooling with 10 kg mass and intended life of 10 years at 95% reliability for NASA/GSFC, and (3) 200 mW at 4-20 K cooling with 10 kg mass and intended life of 10 years at 95% reliability for JPL. Tests were scheduled for completion by mid-1992. (Stacy 1992) No estimate was reported on vibration levels and this is a critical requirement for sensors that require accurate pointing

IV.B.3. Optics and Optical Filters

The optics required for ASTER are comparable to the highest quality space optics produced by US companies for commercial applications. ASTER consists of four separate optical subsystems: VNIR (nadir), VNIR (stereo), SWIR, and TIR. VNIR uses Schmidt-type reflective optics with linear detector arrays. SWIR uses refractive optics with linear detector arrays. TIR used Newtonian-type reflective optics with a mechanical cross-track scanning mirror with staggered detector arrays. (Fujisada and Ono 1993) Most of ASTER's optical elements are being made in Japan, but an undisclosed number of key elements have been subcontracted to US companies because they could not be made in Japan. Large-size optics (~15-inches diameter) are difficult to find in Japan and I believe the facilities do not exist in Japan for producing these large diameter optical elements.

Conventional bandpass optical filter technology in Japan has improved as a result of the ASTER project, but the moderate-bandpass filters required for ASTER have specifications that are not as severe as those used for optical astronomy. The tightest specification ASTER filters are channel 6 (centered at 2.205 + 0.007 micrometer with FWHM 0.04 + 0.010 micrometer, transmission 70%, NERd < 1.3%, and absolute radiometric accuracy < 4%; Fujisada and Ono 1993) and channel 12 (centered at 9.10 + 0.08 micrometer with FWHM 0.350 + 0.080 micrometer, transmission 60%, NEDT of 0.3 K at 300 K, and absolute radiometric accuracy of + 1 K at 300 K; Maekawa et al. 1993). Current designs meet or exceed these specifications.

For non-standard optical filters, the optical filter technology in Japan is significantly lower quality than what is available in the US. For example, for the Airborne ASTER Simulator (AAS) project, TOPCON, a leading Japanese filter manufacturer, was asked to produce linear-variable filters (LVFs) for the 3-5 micrometer and 8-12 micrometer linear AAS detectors. LVFs for the 8-12 micrometer region had never been made by TOPCON previously, but the ASTER Engineering Team wanted TOPCON to develop the capability for future use. Initially, in 1992, TOPCON estimated they could produce LVFs with FWHM ~10% of the center wavelength. The final LVFs delivered in 1993 were 7% (JGI 1993). For comparison, the circular variable filters (CVFs) used in the NASA Infrared Telescope Facility spectrograph are ~0.25% bandpass for the 1-5 micrometer region (Greene and Denault 1994). These CVFs were made by Optical Coating Laboratory, Inc., (OCLI). A design study for JPL by OCLI indicated a cryogenic LVF could be made for the 7.5-14 micrometer region with bandpasses of 2-3% (Mahoney et al. 1990). (OCLI was manufacturing this LVF in 1990. I do not know if the airborne system was completed.) This example illustrates the differences in optical filter manufacturing capabilities of OCLI and other US-based companies versus their counterparts in Japan.

IV.B.4. Data Recording

The on-board tape recorder for JERS-1 was very limited, capable of recording data from only one of the two on-board instruments for a total of about 20 minutes out of each approximately 100 minute orbit (JAROS and Mills 1992). (This assumes contact with a ground-station at least once each orbit which was not true for most orbits.) JERS-1, despite its publicity, was not intended as a full-fledged scientific instrument; it was an engineering test project and met most of its goals.

Future Japanese satellites may not use tape recorders. NASDA has committed itself to development of space-qualified optical disk recorders. Planned optical disk systems will use direct overwrite (eliminating separate pre-erasure and verification steps), multiple stacked disks, larger numerical aperture objective lenses, NRZ signal modulation, higher disk rotation speeds, and 12-inch dual-side glass disks to increase the storage capability and speed of the recorders. Projected capabilities are shown in Table 1. (Fukuda et al. 1992)

NASA, also, has an optical disk recorder under study for the EOS-AM1 platform due to be launched in 1998. Specifications were not available as of mid-1993, but the capacity was projected to be about 30 GByte. Based on this very sketchy information, the recorders being developed by NASA and NASDA appear to be roughly comparable in capabilities.

IV.B.5. System Integration and Science-Project Management

Project management is one area where I feel Japanese remote sensing programs have been very weak. Despite the success of Japanese companies in tailoring products to the consumer market, very little effort was made in the first decade of satellite remote sensing in Japan to work with scientists or other users in designing the instruments. For example, JERS-1 was built to specifications written by the Japanese government's engineering team with a minimal amount of input from the scientific community. Demonstration experiments were made concurrently with the JERS-1 engineering design, but the experiments started so late that no changes could be made in the design. Viewed as an engineering experiment, JERS-1 was generally a success. The only subsystem that did not meet its objectives was the SWIR subsystem built by MELCO. However, viewed as a scientific experiment, JERS-1 had many difficulties: the SWIR problems, misregistered data, and inappropriate settings for the instrumental gain (Nishidai 1993). The scientific failures of JERS-1 and the active involvement of US scientists in the ASTER program led to significant input from the scientific community (and a few potential commercial users) on the ASTER design and operation.

The ASTER program has been a significant learning experience for all of the Japanese scientists and project managers involved. The US ASTER Science and Engineering Team members have taught MITI's scientists how to work interactively with the engineering team, pushing the system performance beyond the engineering team's initial offer and significantly increasing the operational flexibility of the systems. This experience will be invaluable in future science projects, and it may help the private companies with their already successful product development cycles. The Japanese remote sensing satellite program has one significant management advantage over current NASA and DoD programs. MITI and NASDA have a relatively short product cycle for each system. For example, JERS-1 required only six years from initial planning to completion of the mission instruments with an additional two years for system integration. ASTER also will be launched within 10 years of the initial feasibility study. This short product cycle encourages incremental improvement in technology, provides opportunities for testing the new technology as a backup to the previous technology, and may lower the research costs for development of each new system. Total expenditures, however, do not decrease.

The primary Japanese companies involved in the ASTER and JERS-1 projects (NEC, MELCO, Fujitsu, and Hitachi) also seemed to be weak in large-scale system integration.

This may result from MITI's contracting arrangements whereby each company has a separate contract with MITI and does not consult the other companies involved except through MITI/JAROS. It may also just be due to lack of practice among the particular managers and corporate divisions involved (I cannot imagine that companies which have been so successful in commercial ventures would lack experience in large-scale system integration).

IV.B.6. Precision Manufacturing and Quality Control

Japanese electronics companies have a reputation for high quality manufacturing and my own experience, generally, corroborates this. For example, the original detector systems made for the AAS by Graseby had poor quality control and poor-quality assembly (e.g., missing solder joints, miswired detectors, etc.). The replacement detector systems made by Hamamatsu Photonics have not had any problems of this type. (See earlier sections for an evaluation of the detectors' relative performance.) As a second example, NEC's design for the ASTER VNIR requires cross-track pointing of a slaved pair of telescopes (about 14 kg total mass) by as much as 24 degrees off-nadir. Breadboard model tests found a MTBF >55,000 cross-tracking pointing maneuvers, far exceeding both the specification of 13,000 lifetime pointing and the science goal of 27,000 pointing (Shimizu et al 1993). As a third example, MELCO's ASTER SWIR design has a 60 micrometer depth of focus that must be maintained in all thermal conditions. MELCO doesn't expect any difficulties manufacturing and assembling the SWIR components to this precision. However, the poor performance of JERS-1's SWIR, also built by MELCO, leaves room for doubt.

IV.B.7. Ground System Infrastructure and Spaceflight Operations

NASDA has developed a ground system for communications with and control of the many satellites it has launched. NASDA's ground system, however, was located, almost exclusively in the Japanese islands and was designed for a relatively simple level of communication with the Earth-orbiting satellites. JERS-1 was intended to collect data over the entire earth's surface but had a small onboard recorder. As a consequence, NASDA deployed a mobile satellite communications station in northern Sweden. (Existing receivers in Europe could have been used by NASDA, but NADA preferred to install its own receiving station in Sweden.) In the future, NASDA appears to want to eliminate the requirement for ground-stations on foreign territory by (a) developing high-capacity on-board recorders (see section above), and (b) developing satellite to satellite communications. Several test missions are planned for coming years that will develop the technology for satellite to satellite communications. In the meantime, Japan may expand its space communications network, potentially competing with (or at least duplicating) the existing networks for EOSAT, NASA, and SPOT.

Mission operations and data processing for JERS-1 and earlier Japanese Earth-observing satellites was relatively simple. A weekly schedule for JERS-1 would be written in less than a day using computer-aided algorithms to select from the 400-1000 targets (total for two year mission lifetime) requested by principal investigators. The schedule was written only once each week for the following week. Facilities for data processing

were limited; therefore, most of the initial JERS-1 data processing (e.g., cloud cover estimation) was controlled manually by eye.

MITI plans to build a ground data system (largely independent of NASDA) that will automate initial data processing for ASTER and, eventually, permit electronic distribution throughout Japan to qualified investigators. MITI also plans to construct a mission planning center for ASTER that will be capable of handling several thousand data acquisition requests, developing a 7- to 14-day schedule each day, and transferring instrument command sequences to NASA's central control facility each day for up link to ASTER two days later. (MITI's control center will also have the ability to directly up link commands to ASTER and directly down link data and health and safety information from ASTER.) The scheduling algorithms for ASTER will accept emergency priority requests (e.g., imaging after a natural disaster) and weather forecasts up to two days prior to up link of commands to ASTER. This short schedule response and VNIR's 24 degree cross-track pointing will permit VNIR imaging of most sites on the Earth's surface within one week of receipt of the emergency request. The ASTER control center and ground data system represent significant advances in the command and control capability and data processing capability of Japan's space program.

IV.B.8. Testing and Standards

The testing and standards laboratories in Japan are good, but the ASTER program has highlighted two areas in which testing facilities just do not exist in Japan: large spacecraft test facilities and optics test equipment. The spacecraft test facilities (e.g., thermal vacuum and vibration test chambers) in Japan are, apparently, too small to test the entire ASTER system. Some new test facilities are being built in Japan for the ASTER program, but the final integrated system testing will be done in the US. New optics test facilities for ASTER will also be built in Japan because Japan did not have good facilities for measuring MTF, off-axis response, and radiometric calibration. The initial calibration plan for ASTER did not include MTF, off-axis response, and other non-radiometric measurements (Ono and Sakuma 1991). These measurements were added at the request of the US members of the ASTER Science Team. The new facilities being developed for ASTER and the experience of using them will help the Japanese companies produce better space instruments in the future.

The ASTER program is also improving the testing and simulation know-how of NEC, MELCO, and Fujitsu. For example, the Japanese contractors were required to work closely with NASA on a revised computer simulation and analysis of vibrations that might be induced by the ASTER cryocoolers. (The initial reports provided by the Japanese contractors indicated they might have done the analysis improperly. This could cause problems for the EOS-AM1 satellite because excess vibrations from ASTER could significantly degrade the pointing required by other instruments on the EOS-AM1 platform.)

IV.B.9. Remote Sensing Satellite Instruments

Japan plans to launch several Earth-observing satellites in the next decade and will also provide instruments for satellites launched by other countries. Table 2 lists most of these Earth observing satellites and general characteristics of their instruments.

A good example of the current level of Japanese expertise in remote sensing satellite instruments is the Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) whose general specifications are listed in Table 3. ASTER is currently being manufactured and it is scheduled for launch on NASA's EOS-AM1 satellite in 1998. ASTER was originally designed as a resource exploration instrument for mapping geology in arid and semi-arid terrain where mineral and petroleum deposits might be located via satellite remote sensing. After acceptance as a NASA Earth Observing System (EOS) facility instrument, ASTER's mission was changed to land-surface remote sensing for global change studies. However, ASTER's design has changed very little.

The scientific areas ASTER will try to address as part of the EOS program are "(a) geology and soil--compositional and geomorphologic mapping of surface soil and bedrock ..., (b) volcano monitoring--monitoring of eruptions and precursive events ..., (c) carbon cycling and marine ecosystem--[measuring the rate at which atmospheric CO_2 is being fixed] into coral reefs by measuring the [growth] rate of coral reefs, (d) aerosol and cloud ..., (e) evapotranspiration ..., (f) hydrology--understanding of global energy and hydrologic processes and their relationship to global changes, (g) vegetation and ecosystem dynamics-- ... vegetation and soil distribution and changes ..., and (h) land surface climatology ..." (Yamaguchi et al 1993) Combining ASTER data with data from other EOS instruments (particularly MODIS or MISR) will significantly improve the fidelity of the derived results.

ASTER combines the stereo capability of SPOT, a 15-m (at nadir) visible-region pixel size (near SPOT's 10-m pixel size), and Landsat's near-infrared vegetation mapping bands. ASTER goes beyond both of these commercial remote sensing systems by offering same-orbit stereo imaging, five narrow bands in the 1-3 micrometer region which are optimized for mapping key clay minerals in arid terrain, and five bands in the 8-12 micrometer region chosen (at least in part) to discriminate silica content in surface rocks. ASTER gives Japan (and the US) land remote sensing capability superior to most other existing and near-future (non-military) satellite instruments. ASTER data will be archived in both Japan and the US. However, scheduling will be done under the control of the (Japanese) Science Team leader, all data calibration will be done in Japan using proprietary algorithms, and data access policies in Japan will probably differ from those in the US. Consequently, US-based resource exploration companies may be placed at a competitive disadvantage, if ASTER works. If it works, ASTER should be a very successful instrument for land surface mapping.

IV.B.10. Commercialization

The commercial market for remote sensing applications in Japan is, currently, small. The Japanese government has put much less backing into commercial ventures than the US government (including national, state, and local governments and agencies). Consequently, fewer remote sensing products are available commercially in Japan. This may change in the near future. Several Japanese electronics companies have begun marketing systems for the remote sensing community. Fujitsu is marketing a passive ozone sensor operating at 110-GHz. NEC has developed an integrated station for reception of satellite signals followed by processing, display, and interactive interpretation. NEC is also marketing analysis systems optimized for image processing and SAR processing. Sony is trying to sell its digital tape systems for both online and archival

storage of remote sensing data. If these major Japanese companies enter the remote sensing product field, a significant number of commercial products could emerge (as happened with the development of lightweight, inexpensive GPS receivers).

V. Future Directions for Japanese Remote Sensing

Recent political changes in Japan (i.e., the breakup of the Liberal Democratic Party and the accession of a coalition government to power), increasing demands for a better standard of living for Japanese workers, the recent pause in economic growth, and increasing interest in environmental issues are triggering some debate over the future direction of Japan's space and remote sensing programs. However, neither of these programs is threatened with wholesale changes since both enjoy reasonable levels of support from either the government bureaucracy, major corporations, and/or the public. The current debate is over questions of what direction to head, not over whether the programs should exist.

ISAS and NASDA will probably continue to pursue the same endeavors as they have recently pursued. ISAS will continue to pursue an active (but focused and relatively inexpensive) space science research program. ISAS may have increased competition within Monbusho for funds as university researchers seek to limit the growth of ISAS in an effort to obtain increased funding for their own research.

NASDA will pursue improvement of satellite and launch-vehicle technology and will attempt to leapfrog into a leadership position in satellite technology by adapting (heretofore untested in space) commercial systems for use on satellites. NASDA and Monbusho seem to have reached some agreement on cooperation between NASDA and university researchers. If this works well on the upcoming ADEOS mission, it should continue in the future and will improve the scientific quality of NASDA's Earth-observing remote sensing projects. As part of NASDA's increased emphasis on scientific research, an increasing number of NASDA programs will include international instrument teams or principal investigators. However, NASDA's primary focus will remain development of Japan's technological base. Foreign participation in NASDA's projects will be tolerated when necessary but is not likely to be actively sought. Politically, NASDA has to reach some accommodation with MITI--MITI's interest in satellite exploration for non-renewable resources (minerals and petroleum) takes away from NASDA part of the primary reason for NASDA's existence--commercial development of space.

MITI's entry into space-based remote sensing adds a new dimension to the Japanese government's space program that is virtually non-existent in the US. MITI, like NASDA and ISAS, pushes technology development, but MITI's primary purpose is economic (commercial) and political (trade) development. Remote sensing may fit MITI's political and economic goals nicely. It can be used for resource exploration, land-use planning, and as a (very small) political favor. If optical remote sensing proves to be a useful tool for locating petroleum and mineral resources, then the infrastructure MITI is developing may give Japanese exploration companies a competitive advantage. (I emphasize that optical remote sensing has not, yet, proven itself as a significant aid in locating mineral or petroleum deposits, but it has some potential.) This advantage, combined with (a) MITI's active promotion of trade and development and (b) Japan's increasing importance in East Asian trade, may be sufficient to offset the historical political advantage the US has had in negotiations with East Asian countries.

The near-future Earth-observing satellite missions planned by NASDA are listed in Table 2. Additional NASDA missions planned are listed in Table 4. MITI has plans for two future satellite instruments: (1) an advanced version of ASTER and (2) a multi-polarization and/or multi-frequency SAR (JAROS 1993). MITI also has a near-term plan to build a multi-polarization and multi-frequency airborne SAR (JAROS 1993). Conceptual design studies for the airborne SAR have begun and engineering development should begin in the next one to two years. Recently, MITI has also begun looking at a cooperative development project with the US companies which are advertising a one-meter resolution optical satellite sensor. These projects will not give Japan the ability to produce a space station or a MILSTAR satellite, but they will bring Japan up to the technology level where they could embark on such a project.

VI. Potential Impact on US National Security

Japan's space program and remote sensing program can have four potential impacts on US national security: (1) enhancing Japan's economic competitive advantage, (2) increasing Japan's political leverage, (3) degrading the US' potential military capability, and (4) improving Japan's potential military capability. The fourth area will not be a problem for the US as long as Japan remains a militarily non-aggressive nation and generally accepts US foreign policy. Japan's remote sensing program will affect the US' military capability only if the US does not continue to maintain commercial remote sensing instruments in space. Japan's remote sensing program will give Japan additional political leverage in trade with developing countries, but the effect will be tiny compared to Japan's overall economic strength. Thus, in the current situation, Japan's space-based remote sensing program can significantly affect the US only in the first area--giving Japanese corporations an economic advantage over their foreign competitors.

Commercial exploitation of remote sensing has been slow to develop. Four applications in which remote sensing has been used are (1) resource exploration and geological mapping, (2) land-use planning and monitoring, (3) environmental monitoring, and (4) disaster prevention and damage assessment. The remote sensing systems under development for MITI can be used for other applications, but they are being designed for resource exploration and geological mapping. Research tests by NASA, ERSDAC, British Petroleum, Geophysical Environmental Research, GeoSpectra, and other groups have demonstrated that satellite and airborne instruments can map regional-scale geological structures and identify surface minerals in particular conditions, but the response from mining and oil companies has been mixed. British Petroleum had a remote sensing research division until about two years ago, but they closed the division because they felt it was not cost-effective. In contrast, Texaco last year placed an order for a dedicated, multi-spectral, airborne scanner that will be delivered in a couple years.

If remote sensing does become more widely used (and useful) for resource exploration, then Japanese companies may have a significant competitive advantage in the future by virtue of their easy (and cheaper) access to data from Japan's remote sensing satellites. Japan has usually restricted satellite data access to the principal investigator who requested it and groups working on research contracts for Japanese government agencies. Most of the groups working on research contracts with ERSDAC are Japanese mineral and petroleum exploration companies. NASA and EOSAT, by contrast, have charged significantly higher prices to commercial ventures than to educational research projects for

access to Landsat data. (This pricing was usually at the direction of Congress based on Congress' desire to make space-based remote sensing self-financing, if possible.) Consequently, Japanese resource exploration companies are likely to have significantly easier (and cheaper) access to remote sensing data for potential mineral deposit locations.

The other applications in which remote sensing data have been used (land-use planning, environmental monitoring, and disaster prevention) do not have large commercial markets at the present time. The primary customers are local, state, and national governments. In the future, however, new applications may be found for remote sensing data with larger commercial markets. In that event, data access will become a more critical concern for the new commercial ventures. Japan's restrictions on data access, particularly NASDA's, are one reason why cooperative programs between NASDA and NASA, so far, have not been a two-way street but, rather, about a one and one-half way street (with Japan receiving more than it provides).

Politically, Japan has already begun using remote sensing projects to gain leverage on mineral exploration rights. For example, the Japan Intellectual Cooperation Agency (JICA) has established remote sensing research centers in Indonesia and China in cooperation with local agencies. These research centers have, almost exclusively, studied oil and mineral exploration. JICA and the Japan National Oil Company (JNOC) have also worked closely with research groups in Algeria, Saudi Arabia, Peru, and other countries on oil exploration via remote sensing. These contacts and grants are useful for the receiving country, but they also promote contact with scientific and political figures who may be able to help Japanese companies get exploration rights for oil and minerals.

Earlier, I noted that in the world's current political and military situation, Japan's remote sensing and space programs will have no effect on either Japan's or the US's military capabilities. What is the current world situation changes? Remote sensing and space technology are classical examples of dual-use technology so their military implications depend, critically, on Japan's political intentions. For example, one of the goals of the joint US-Japan ASTER Science Team is a digital elevation map (DEM) for all continents with (elevation) accuracy of order 7-30 meters at horizontal resolution of 15 meters (Lang and Welch 1994). (For comparison, SPOT3 has vertical accuracy of 10 meters with horizontal resolution of 10 meters and the best USGS DEMs have vertical accuracy of 7 meters with horizontal resolution of 30 meters (Topographic Science Working Group 1988).) Furthermore, the imaging capability Japan will have after its current generation of sensors is launched (including the launch of ASTER on a NASA satellite) will match or exceed the non-military capability of all other countries. Japan's remote sensing and space technology will be sufficient for most modern military operations, but it is not sufficient for (1) intelligence and surveillance tasks, (2) real-time command, control, and communications, and (3) world-wide force projection or deployment.

Finally, how does the Japanese remote sensing program degrade the US' military capabilities? To understand this, one needs to understand that the US military relies on "commercial" remote sensing systems, such as Landsat, to augment the military satellite-imaging systems for logistical planning, mapping, and other tasks. EOSAT provided Landsat imagery shortly before Desert Storm to DoD. (This was publicly disclosed about a year later.) Military satellites, such as DMSP, have similar capabilities but probably cannot satisfy these general military requirements. Consequently, recent problems with the Landsat program and NASA's selection of ASTER as an EOS facility instrument could create a potential military problem. If the US does not have an orbiting instrument

comparable to Landsat, will the US military ask Japan or France for data prior to its next military operation?

VII. Conclusions

The Japan National Space Development Agency (NASDA) and the Japan Ministry of International Trade and Industry (MITI) in the past 10-15 years have significantly improved the "commercial" (non-military) satellite remote sensing and space technology capabilities of Japanese companies. (The first meteorological satellite built in Japan and launched on a Japanese booster was launched in 1981.) At the current time, Japanese remote sensing technology generally seems to be about one - two generations behind that of the US. However, Japan has many missions (and instruments) planned for the next five years. If the upcoming satellites and instruments function as intended, then Japan may have significantly narrowed the gap in space-based remote sensing technology. Five years from now, Japan will not be building a space station or a MILSTAR satellite, but Japanese companies should be approximately at the level where they can start to build a space station or MILSTAR satellite.

There are four areas in which I feel Japanese groups have good research or technology programs in the remote sensing field. The Center for Climate System Research (CCSR) under Professor Taroh Matsuno has recently begun studies on regional climate that may provide significant insight in the coming years. CCSR also has a good research program under Professor Teruyuki Nakajima who is studying radiative transfer modeling and space-based remote sensing of clouds. The Meteorological Research Institute under Dr. Tsutomu Takashima is also doing good radiative transfer modeling, but their work is directed toward understanding multiple scattering between the atmosphere and an inhomogeneous surface. Finally, Japanese companies appear to be good at manufacturing products that meet exacting tolerance specifications so their manufacturing technologies merit further study.

Japan's scientific research in other areas of remote sensing has not been cutting-edge. Japanese research has focused primarily on areas of local concern, particularly those areas involving local economic issues. This research has been hampered by limited funds, computing resources, data for model developing and testing, and instruments (satellite and airborne) for field data collection. Some of these limitations are being addressed by recent efforts by Japan's Ministry of Education, Science, and Culture (Monbusho) to upgrade university research facilities and increased cooperation between Monbusho and NASDA on future satellite projects, but these changes are too recent to have had a significant impact.

For remote sensing and space technology, Japan's approach, generally, has been to make frequent incremental improvements. Some of Japan's planned missions/instruments will depart from that philosophy by attempting to leapfrog several generations of inflight testing. NASDA and MITI are trying to adapt the latest laboratory (or commercial) products for space use. These products have passed rigorous testing under Earth-surface conditions, but have never been used in space so their reliability is unknown.

If one excludes US and Russian military satellites, then Japan's space-based optical remote sensing capability in 1998 may be the best in the world. The Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) that MITI is providing to NASA for inclusion on a NASA Earth Observing System (EOS) satellite, will

provide stereo imaging comparable to SPOT and higher spectral resolution (imaging) in the 2 - 3 micrometer and 8 - 12 micrometer regions than any existing (or planned) commercial space sensors. NASA and other scientists will use the data from ASTER for many valuable climatological and environmental studies, but ASTER's raison d'etre is mineral and petroleum exploration.

MITI is a relative newcomer to space remote sensing in Japan, but it has a significant amount of political and financial power. MITI's interests in space remote sensing are economic, political, and technological. First, MITI wants to help Japanese companies locate mineral resources the Japanese economy needs for continued growth. Second, MITI's remote sensing programs are both helping Japan expand ties with developing countries that are relatively rich in mineral resources and providing opportunities for cooperation on space and environmental projects with the US and Europe. Third, MITI wants to develop the technology base of Japanese companies in the space remote sensing field. MITI has been more receptive to international ventures than NASDA, in part, because MITI has a role in Japan's foreign policy (i.e., trade) and, in part, because MITI structures the agreements so that Japanese companies learn from their foreign counterparts. Consequently, MITI can more easily tie its projects to the economic and political gains from international cooperation.

NASDA, the "traditional" space agency in Japan, has also sponsored several space remote sensing projects. NASDA's primary goals for these projects have been development of Japanese technology (either at NASDA or at contracting companies) and establishment of opportunities for commercialization of space. Now, science is becoming a legitimate reason for conducting space missions in NASDA, and cooperation between NASDA and Monbusho is starting to occur. This change has also meant that NASDA is more interested in cooperating with other countries on international projects. NASDA still has a primary goal of developing Japanese technical capability so NASDA is reluctant to go outside Japan for any new instruments that can be built in Japan. NASDA is quite interested in supporting international projects out of a sense of international responsibility (and a desire to contribute to environmental protection for humanity), but it prefers to use completely Japanese-made instruments.

Monbusho's Institute of Space and Astronautical Sciences (ISAS) is the third major government player in space remote sensing in Japan. ISAS is quite different from NASDA and MITI (and largely independent of them) because ISAS is focused primarily on space science research.

VIII. Recommendations

Based on my experience working in Japan and this assessment of Japanese remote sensing technology, there are several recommendations I wish to offer. The first three can be accomplished by AFOSR and AOARD. The final three are more general.

First, there are two areas in which AOARD contacts can definitely benefit the USAF and US companies: (1) the geophysics research underway at the Meteorological Research Institute and the Center for Climate System Research and (2) the precision manufacturing technology and expertise of Japanese companies. The work in these two areas in Japan is good and should be known in the US scientific or corporate communities, respectively. Infrared detectors and materials processing for infrared detectors may be a third area in

which Japanese groups have some edge on current US efforts, but this should be examined by someone with more experience in this field.

Second, AOARD could try to establish some liaison between (1) the Meteorological Research Institute and the Center for Climate System Research in Japan and Phillips Laboratory and (2) the Electrotechnical Laboratory in Japan and the appropriate AF laboratory (Wright Laboratory, Phillips Laboratory, Rome Laboratory). The electronics research work at ETL may be regularly published in English-language journals, but someone familiar with the field will need to provide information on this.

Third, Japanese space-based remote sensing technology, generally, is not as advanced as US technology in this field. However, AOARD should review the status of Japanese space technology in a few years to see what progress has occurred and what potential applications have evolved.

At the DoD level, DoD needs to evaluate what remote sensing capabilities are needed for war planning and war-fighting. These needs may be satisfied by current or planned DoD and National Assets, but the use of Landsat data for Desert Shield indicates there are gaps. To the extent these gaps can be filled by "commercial" remote sensing satellites, such as Landsat, coordination (or convergence) among NASA, DoD, and NOAA is needed. Congress has mandated such convergence for the next generation Defense Meteorological Satellite Program (DMSP). DMSP has had problems converging the disparate requirements of the five agencies (AF, Navy, Army, NOAA, NASA) involved, but the convergence may, eventually, save money. If DoD does not take some role in ensuring the US launches dual-use remote sensing satellites, these satellites may not be available in an emergency.

At a more general level, future international projects sponsored by US agencies need to ensure the projects will develop both the US' and the international partner's technology bases. The international agreements should also ensure comparable access (and pricing) for remote sensing data products for users in all countries involved. These steps will help the agreements be more truly cooperative and ensure one country does not receive a competitive advantage as a result of the agreement.

Finally, a reduction of product cycle timelines based on smaller, more-focused satellites (when possible) provides more opportunities to incorporate new technology (and test it as back-up system) and improves the continuity of expertise. Unlike major, modern weapons systems which require complexity to function well, many remote sensing systems can be designed to fit this idea, if funding is available.

References and Bibliography

1) Agency of Industrial Science and Technology (AIST), "AIST Tsukuba Research Center," English Pamphlet (1991)

2) Amber Research Corporation, "InSb 256 x 256 Arrays," Santa Barbara, California (1993)

3) Asia Air Survey Co., Ltd., "Surveying is Only the Shell of Our Business," English Pamphlet (1991)

4) Center for Climate System Research (CCSR), "Tokyo Daigaku Kikkou System Kenkyu Center," Japanese Pamphlet (translated by Ms. Miyuki Hase in 1994) (1991)

5) Chan, C.K., E. Tward, and W.W. Burt, "Overview of Cryocooler Technologies for Space-based Electronics and Sensors," Advances in Cryogenic Engineering 35, pp. 1239-1250 (1990)

6) Davey, G., "Review of the Oxford Cryocooler," Advances in Cryogenic Engineering 35, pp. 1423-1430 (1990)

7) Earth Environment Observation Committee, English Pamphlet (1992)

8) Earth Resources Satellite Data Analysis Center (ERSDAC), English Pamphlet (1993)

9) Electrotechnical Laboratory (ETL), English Pamphlet (1992)

10) Ezaka, T., Y. Kannari, F. Mills, H. Watanabe, M. Sano, and S.H. Chang, "Laboratory Test Results for an Airborne ASTER Simulator," Proceedings of the SPIE Conference: sensor systems for the early Earth observing system platforms, vol. 1939, ed. W.L. Barnes, pp. 210-221 (1993)

11) Fujisada, H., and A. Ono, "Anticipated Performance of ASTER Instrument in EM Design Phase," Proceedings of the SPIE Conference: sensor systems for the earthly Earth observing system platforms, vol. 1939, ed. W.L. Barnes, pp. 187-197 (1993)

12) Fujisada, H., H. Nakayama, and A. Tanaka, "Compact 128 InSb Focal Plane Assembly for Thermal Imaging," Proceedings of the SPIE Conference: infrared technology XVI, vol. 1341, Ed. I.J. Spiro, pp. 80-91 (1990)

13) Fujisada, H., Personal Communication (1991)

14) Fujitsu, "Upper Atmosphere Ozone Monitoring System," English Technical News Pamphlet (1993)

15) Fukuda, T., S. Yamamoto, H. Anegawa, M. Kasuya, and D. Maeusli, "Study of a High-speed Optical Disk Data Recorder for Space Application," 43rd Congress of the International Astronautical Federation, Paper IAF-92-0103, 28 Aug - 5 Sep 1992, Washington, DC (1992)

16) Geological Survey of Japan, English Pamphlet (1990 & 1993)

17) Greene, T., and A. Denault, "CSHELL (Cryogenic Echelle Spectrograph) User's Manual Revision 2.0 b1," NASA Infrared Telescope Facility, Institute for Astronomy, University of Hawaii, Honolulu, Hawaii (1994)

18) Hino, H., M. Takei, H. Ono, R. Nagura, Y. Narimatsu, M. Hiramatsu, H. Harada, and K. Ogikubo, "Optical Sensor System for Japanese Earth Resources Satellite 1," Proceedings of the SPIE Conference: future European and Japanese remote sensing sensors and programs, vol. 1490, ed. P.N. Slater (1991)

19) Isoda, M., T. Takenouchi, M. Kimata, H. Akao, H. Michioka, and M. Ono, "Design Challenges of ASTER in Shortwave Infrared Spectral Region," Proceedings of the SPIE Conference: instruments for the early Earth observing platforms, vol. 1939, ed. W.L. Barnes, pp. 170-175 (1993)

20) Iwasaki, N., N. Hara, M. Kajii, Y. Tange, Y. Miyachi, R. Sato, and K. Inoue, "Mission Overview of ADEOS Program," Proceedings of the SPIE Conference: future European and Japanese remote sensing sensors and programs, vol. 1490, ed. Slater (1991)

21) Japan Climatic Data Centre, "New Data Base Challenge to Global Climatic Change," English pamphlet (1993)

22) Japan Observation System Organization (JAROS), English pamphlet (1991)

23) Japan Observation System Organization (JAROS), "JAROS News," March 1993 (1993)

24) Japan Observation System Organization (JAROS) and Mills, F.P., "The Advanced Spaceborne Thermal Emission and Reflection Radiometer", English pamphlet published by JAROS (1992)

25) Japan Observation System Organization (JAROS) and Mills, F.P., "The Japan Earth Resources Satellite", English pamphlet published by JAROS (1992)

26) Japex Geoscience Institute (JGI), Report on Research for JAROS for JFY 1992, Japanese report (1993)

27) Johnson-Freese, J., "Japanese Space Policy for the 21st Century", 43rd Congress of the International Astronautical Federation, Paper IAF-92-0203, Aug 28 - Sep 5, 1992, Washington, DC (1992)

28) Kawada, M., & H. Fujisada, "Mechanical Cooler Development Program for ASTER," Proceedings of the SPIE Conference: future European and Japanese remote sensing sensors and programs, vol. 1490, ed. P.N. Slater (1991)

29) Lang, H.R., and R. Welch, "Algorithm Theoretical Basis Document (User's Guide) for ASTER Digital Elevation Models (DEMs)," JPL Publication D-11628 (1994)

30) Maekawa, T., O. Nishihara, Y. Aoki, K. Tsubosaka, and S. Kitamura, "Design Challenges of ASTER in Thermal Infrared Spectral Region," Proceedings of the SPIE Conference: sensor systems for the early Earth observing system platforms, vol. 1939, ed. W.L. Barnes, pp. 176-186 (1993)

31) Mahoney, C., C. LaBaw, H. Sobel, and A. Kahle, "Thermal Infrared Imaging Spectrometer: an advanced optics technology instrument," Proceedings of the SPIE Conference: Imaging Spectroscopy of the Terrestrial Environment, vol 1298, ed. G. Vane, pp. 87 - 92 (1990)

32) Meteorological Research Institute, "Outline of Research Activities," English Pamphlet (1992)

33) Mills, F.P., Y. Kannari, H. Watanabe, M. Sano, and S.H. Chang, "Thermal Airborne Multispectral ASTER Simulator and Its Preliminary Results," Advances in Space Research 14, pp. 49-58 (1994)

34) National Space Development Agency (NASDA), English pamphlets describing history & missions (1991-1993)

35) Nishidai, T., "Early Results from 'Fuyo-1' Japan's Earth Resources Satellite (JERS-1)," International Journal of Remote Sensing 14, pp. 1825-1833 (1993)

36) Ohmori, Y., I. Arakawa, A. Nakai, and K. Tsubosaka, "Cooling System for Short-wave Infrared Radiometer of JERS-1 Optical Sensor," Proceedings of the SPIE Conference: future European and Japanese remote sensing sensors and programs, vol 1490, ed. P.N. Slater (1991)

37) Ono, A., and F. Sakuma, "ASTER Instrument Calibration Plan," Proceedings of the SPIE Conference: sensor systems for the early Earth observing system platforms, vol. 1939, ed. W.L. Barnes, pp. 198-209 (1993)

38) Ono, A., and F. Sakuma, "ASTER Calibration Concept," Proceedings of the SPIE Conference: future European and Japanese remote sensing sensors and programs, vol. 1490, ed. P.N. Slater (1991)

39) Ono, M., and Y. Nemoto, "Synthetic Aperture Radar of JERS-1," Proceedings of the SPIE Conference: future European and Japanese remote sensing sensors and programs, vol 1490, ed. P.N. Slater (1991)

40) Remote Sensing Technology Center of Japan (RESTEC), English Pamphlet (1993)

41) Shimizu, Y., Y. Narimatsu, and M. Hiramatsu, "Design Challenges of ASTER in Visible and Near-Infrared Spectral Region," Proceedings of the SPIE Conference: sensor systems for the early Earth observing system platforms, vol 1939, ed. W.L. Barnes, pp. 161-169 (1993)

42) Stacy, W.D., "Diaphragm Stirling Cryocooler Developments," Cryogenics 32, pp. 138-142 (1992)

43) Tanaka, T., "Japanese Earth Observing Systems in the 1990s," Advances in Space Research 11, pp. 201-211 (1991)

44) Tokai University Space Information Center, English pamphlet (1990)

45) Topographic Science Working Group, "Topographic Science Working Group Report to the Land Processes Branch, Earth Science and Applications Division, NASA Headquarters," Lunar and Planetary Institute, Houston, Texas (1988)

46) Watanabe, H., M. Sano, F.P. Mills, S.H. Chang, and S. Masuda, "Airborne and Spaceborne Thermal Multispectral Remote Sensing," Proceedings of the SPIE Conference: future European and Japanese remote sensing sensors and programs, vol. 1490, ed. P.N. Slater (1991)

47) Yamaguchi, Y., H. Tsu, and H. Fujisada, "Scientific Basis of ASTER Instrument Design," Proceedings of the SPIE Conference: sensor systems for the early Earth observing system platforms, vol. 1939, ed. W.L. Barnes, pp. 150-160 (1993)

Tables

Table 1. Projected Optical Disk Capabilities for Near-Future NASDA Satellites (Fukuda et al. 1992)

	ADEOS-2 Model (Type A)	ADEOS-2 Model (Type B)	Advanced Model (Target)
Media Type	Optical Disk (20 cm)	Optical Disk (30 cm)	Optical Disk (30 cm)
Capacity	27 GByte	45 GByte	45 GByte
Data Rate	60 Mbps maximum (30 Mbps X 2 ch)	60 Mbps maximum (30 Mbps X 2 ch)	120 Mbps maximum (60Mpbs X 2 ch or 30 Mpbs X 4 ch)
Access Type	Random Access	Random Access	Random Access
Interface	MDR compatible	MDR compatible	MDR compatible or CCSDS packet or SCSI
Life	5 year	5 year	5 year
Mass	40 kg	50 kg	50 kg
Size	30 x 30 x 30 (cm) (volume: 27 liters)	40 x 40 x 30 (cm) (volume: 48 liters)	40 x 40 x 30 (cm) (volume: 48 liters)
Power	140 W maximum	150 W maximum	150 W maximum

Either type A or type B is planned for use as an engineering demonstration and backup recorder on Japan's ADEOS-2 satellite. ADEOS-2 is scheduled for launch in 1999.

Table 2. Planned Japanese Earth-Observing Satellites (NASDA 1993, Tanaka 1991)

Launch	Satellite Primary Objectives (Instruments)	Design Started
1994	Geostationary Meteorological Satellite (GMS) #5	1988
	Multi-band Observations at 0.55-0.9, 6.5-7.0, 10.5-11.5, & 11.5-12.5 mm with spatial resolution at nadir of 1.25 km in visible and 5.0 km in infrared	
	Search and Rescue Transponder for Emergencies at Sea	
1995	Advanced Earth Observing Satellite (ADEOS)	1988
	Ocean Color and Temperature Scanner (OCTS)	NASDA
	Advanced Visible and Near-Infrared Radiometer (AVNIR)	NASDA
	NASA Scatterometer (NSCAT)	NASA
	Total Ozone Mapping Spectrometer (TOMS)	NASA
	Polarization and Directionality of the Earth's Reflectances (POLDER)	Franc
	Interferometric Monitor for Greenhouse Gases (IMG)	MITI
	Improved Limb Atmospheric Spectrometer (ILAS)	*
	Retroreflector in Space (RIS)	*
	* Japan Environment Agency	
1995	Tropical Rainfall Measuring Mission (TRMM) **	
	Precipitation Radar (PR)	NASDA
	TRMM Microwave Imager (TMI)	NASA
	Visible and Infrared Scanner (VIRS)	NASA
	Clouds and the Earth's Radiant Energy System (CERES)	NASA
	Lightning Imaging Sensor (LIS)	NASA
	** TRMM is a NASA spacecraft being launched by NASDA with one instrument from NASDA	
1999	ADEOS-2 (Japan Polar Orbiting Platform--JPOP)	

Table 3. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) (JAROS and Mills 1992)

Visible and Near-Infrared Radiometer (VNIR)	0.52 - 0.60 μm	0.63 - 0.69 μm
	0.76 - 0.86 μm (nadir)	
	0.5 % NEDr radiometric resolution	
	15 m geometric resolution (nadir) (21.3 mrad)	
	all bands nadir viewing	
VNIR Stereo	0.76 - 0.86 μm (aft-viewing)	
	0.5 % NEDr radiometric resolution	
	same orbit stereo-pair imaging	
Short-wave Infrared Radiometer (SWIR)	1.600 - 1.700 μm	0.5 % NEDr
	2.145 - 2.185 μm	0.8 % NEDr
	2.185 - 2.225 μm	0.8 % NEDr
	2.235 - 2.285 μm	1.0 % NEDr
	2.295 - 2.365 μm	1.0 % NEDr
	2.360 - 2.430 μm	1.3 % NEDr
	30 m geometric resolution (nadir) (42.6 mrad)	
	all bands nadir-viewing only	
Thermal Infrared Radiometer (TIR)	8.125 - 8.475 μm	
	8.475 - 8.825 μm	
	8.925 - 9.275 μm	
	10.25 - 10.95 μm	
	10.95 - 11.65 μm	
	NEDT 0.3 K at 300 K	
	90 m geometric resolution (nadir) (127.6 mrad)	
	all bands nadir-viewing only	

Table 4. Planned NASDA Spaceflight Missions (NASDA 1993)

Launch	Satellite / Primary Objectives	Design Started
1994	Engineering Test Satellite (ETS) #6	1985
	Inter-orbit and Satellite to Ground Communications	
	Ni-H2 Batteries	
	Thrusters and Attitude Control System	
1995	Engineering Test Satellite (ETS) #7	1990
	Rendezvous Docking and Space Robotics	
1997	Communication & Broadcasting Engineering Test Satellite (COMETS)	1990
	Inter-orbit Communications	
	Wideband Regional Broadcasting Using Ka-band	
	Communications Relay Between Mobile Earth Stations Using Ka-and O-bands	
1998	Optical Inter-orbit Communications Engineering Test Satellite	
199?	H-II Orbiting Plane (HOPE)	1985
	Japan's Space Shuttle	
?	Japanese Experimental Module for US Space Station	1985

Appendix

List of Japanese Organizations Involved in Remote Sensing in Japan
with Addresses and Points of Contact

Agency of Industrial Science and Technology (MITI)
General Coordination Department
Tsukuba Administration Office
1-1-4 Higashi, Tsukuba-shi, Ibaraki-ken 305
Telephone: 81-298-54-2101

Asia Air Survey Co., Ltd
Head Office
2-18 Shinjuku 4, Shinjuku-ku, Tokyo 160
Telephone: 81-3-5379-2155; Telefax: 81-3-5379-2156

Center for Climate System Research
The University of Tokyo
4-6-1 Komaba, Meguro-ku, Tokyo 153
Telephone: 81-3-5453-3950; Telefax: 81-3-5453-3964
Director: Prof. Taroh Matsuno (specialty: atmospheric dynamics)
Other staff: Associate Prof. Teriyuki Nakajima
(radiative transfer, remote sensing, cloud properties)

Central Research Institute of Electric Power Industry
2-11-1 Iwato-kita, Komae-shi, Tokyo 201
ASTER: Hirokazu Kobayashi
Telephone: 81-3-3480-2111; Telefax: 81-3-3480-1942

Central Research Institute of Electric Power Industry
1546 Abiko, Abiko-shi, Chiba-ken 270-11
ASTER: Masafumi Mizutori
Telephone: 81-471-82-1181: Telefax: 81-471-83-2966

Chiba University
1-33 Yayoi-cho, Chiba-shi, Chiba-ken 260
ASTER: Takashi Ishiyama
Telephone: 81-43-290-3851; Telefax: 81-43-290-3857

Earth Resources Satellite Data Analysis Center
Technical Department
Forefront Tower, 5th Floor
3-12-1 Kachidoki, Chuo-ku, Tokyo 104
Telephone: 81-3-3533-9380; Telefax: 81-3-3533-9383
ASTER Science Team Leader: Dr. Hiroji Tsu
JGI Employees on loan to ERSDAC in 1993: Mr. Ikuya Ohtomo, Mr. Takashi Nishidai
ASTER Ground Data System: Vu Saito
Technical Department Assistant General Manager: Kazuhiko Yoshida

Electrotechnical Laboratory (ETL)
1-1-4 Umezono
Tsukuba-shi, Ibaraki-ken 305
Telephone: 81-298-54-5013
ASTER Sensor Committee Chair: Dr. Hiroyuki Fujisada
Telephone: 81-298-58-5463; Telefax: 81-298-58-5523
ASTER Mechanical Cooler: Masakuni Kawada

Fujitsu Laboratories, Ltd
10-1 Morinosato-Wakamiya, Atsugi 243-01
Telephone: 81-462-48-3111 x 2410; Telefax: 81-462-48-5193

Fujitsu Limited
1015 Kamikodanaka, Nakahara-ku, Kawasaki 211
Cryocooler for SWIR on JERS-1: Y. Ohmori, I. Arakawa, A. Nakai, and K. Tsubosaka

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ASTER: Hiromichi Maruyama
Telephone: 81-298-64-1111; Telefax: 81-298-64-1803
ASTER: Yoshifumi Yasuoka
Telephone: 81-298-51-6111; Telefax: 81-298-51-4732

Geological Survey of Japan
1-1-3 Higashi, Tsukuba-shi, Ibaraki-ken 305
ASTER: Hajime Kayane
Telephone: 81-298-54-3766; Telefax: 81-298-54-3533
ASTER: Ryoichi Kouda
Telephone: 81-298-54-3637; Telefax: 81-298-56-4989
ASTER: Minoru Urai
Telephone: 81-298-54-3619; Telefax: 81-298-54-3533
ASTER Geological Remote Sensing: Mr. Tsuneo Matsunaga
Telephone: 81-298-54-3584; Telefax: 81-298-54-3533
ASTER Geological Remote Sensing: Dr. Yasushi Yamaguchi
Telephone: 81-298-58-2472; Telefax: 81-298-56-4989
Geothermal Research & ASTER Digital Elevation Model: Dr. Yoshinori Miyazaki
Telephone: 81-298-56-7783; Telefax: 81-298-52-0283
ASTER Ground Data System: Dr. Isao Sato
Telephone: 81-298-54-3616; Telefax: 81-298-54-3533

Hamamatsu Photonics KK
1126 Ichino-cho, Hamamatsu 435
Infrared Detector Manufacturing Manager: H. Nakayama
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The Institute of Industrial Science
University of Tokyo
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Remote Sensing Program: Prof. Mikio Takagi
Telephone: 81-3-3479-0289; Telefax: 81-3-3402-6226

Institute of Physical & Chemical Research
Earth Science Laboratory
21 Hirosawa, Wako-shi, Saitama 301-02
ASTER: Motoaki Kishino
Telephone: 81-484-61-1111; Telefax: 81-484-62-1449

Japan National Oil Corporation
2-2-2 Uchisaiwai-cho, Chiyoda-ku, Tokyo 100
ASTER: Yoshikazu Yaguchi
Telephone: 81-3-3597-7628; Telefax: 81-3-3593-8320

Japan Petroleum Exploration Corporation
Akasaka Twin Tower, East Wing, 10th Floor
2-17-22 Akasaka, Minato-ku, Tokyo 107

Japan Resources Observation System Organization
Kamichi Building
3-15-3 Nishi-Shinbashi, Minato-ku, Tokyo 105
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Executive Managing Director: Shoichi Hashimoto
Airborne ASTER Simulator project manager: Dr. Atsushi Ando
Technology Department Assistant Manager: Mr. Sadao Yukawa
ASTER Instrument Manager: Dr. Masahiko Kudoh

Japex Geoscience Institute, Inc
Akasaka Twin Tower, East Wing, Third Floor
2-17-22 Akasaka, Minato-ku, Tokyo 107
Telephone: 81-5570-8910; Telefax: 81-3-3584-0563
Research Department General Manager: Dr. Ikawa
Deputy General Manager: Dr. Hiroshi Watanabe
Remote Sensing Manager: Mr. Toshio Osanai
Telephone: 81-3-5570-8909

Keio University
4-1-1 Hiyoshi, Kouhoku-ku, Yokohama-shi, Kanagawa 223
ASTER: Naotatsu Shikazono
Telephone: 81-45-563-1114; Telefax: 81-45-563-1650

Metal Mining Agency of Japan
1-24-14 Toranomon, Minato-ku, Tokyo 105
ASTER: Takahisa Yamamoto
Telephone: 81-3-3503-2801; Telefax: 81-3-3503-0570

Meteorological Research Institute
1-1 Nagamine, Tsukuba-shi, Ibaraki-ken 305
ASTER Atmospheric Remote Sensing and Correction for Temperature Retrievals:
Keiichi Fukui, Yozo Takayama
Telephone: 81-298-51-7111; Telefax: 81-298-51-3730
Radiative Transfer and Scattering Theory in the Atmosphere: Dr. Tsutomu Takashima
Telephone: 81-298-51-7111; Telefax: 81-298-56-0644

Mitsubishi Electric Corporation
Kamakura Works
Space Systems Department
325 Kamimachiya, Kamakura, Kanagawa 247
SAR for JERS-1: Makoto Ono

Mitsui Mining & Smelting Co., Ltd
2-1-1 Nihonbashi-Muromachi, Chuo-ku, Tokyo 103
ASTER: Tomoyuki Takemura
Telephone: 81-3-3246-8131; Telefax: 81-3-3246-8130

National Institute for Environmental Studies
16-2 Onogawa, Tsukuba-shi, Ibaraki-ken 305
ASTER: Tadakuni Miyazaki
Telephone: 81-298-51-6111; Telefax: 81-298-51-4732

National Institute of Agro-Environmental Sciences
3-1-1 Kannondai, Tsukuba-shi, Ibaraki-ken 305
ASTER: Genya Saito
Telephone: 81-298-38-8225; Telefax: 81-298-38-8199

National Research Laboratory of Metrology
1-1-4 Umezono, Tsukuba-shi, Ibaraki-ken 305
ASTER Instrument Calibration: Dr. Akira Ono, Fumihiro Sakuma
Telephone: 81-298-54-4117; Telefax: 81-298-54-4099

National Space Development Agency of Japan (NASDA)
Earth Observation Program Office
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Future Earth Observing Programs: Tasuku Tanaka

National Space Development Agency of Japan (NASDA)
Tsukuba Space Center
2-1-1 Sengen, Tsukuba-shi 305
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Space Systems Development Division
4035, Ikebe-cho, Midori-ku, Yokohama 226
Telephone: 81-45-939-2400; Telefax: 81-45-939-2572
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Space Systems Division
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JGI Employee on Loan to RESTEC from June 1994: Mr. Yoshiaki Kannari

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Science University of Tokyo
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